TEST ENGINEERS' HANDBOOK

DEALING WITH THE TESTING OF ENGINES, INCLUDING AERO ENGINES, MATERIALS, FUELS, AND LUBRICATING OILS

Prepared by a Staff of Technical Experts under the direction of

E. MOLLOY

WITH ONE HUNDRED AND FIVE ILLUSTRATIONS

GEORGE NEWNES LIMITED
TOWER HOUSE, SOUTHAMPTON STREET, STRAND
LONDON, W.C.2

THE "COMPLETE ENGINEER" SERIES

Prepared by a Staff of Technical Experts
under the Direction of E. MOLLOY.

Published 1941
Reprinted 1941

PRINTED IN GREAT BRITAIN BY HAZELL, WATSON AND VINEY, LTD., LONDON AND AYLESBURY

PREFACE

THE testing of engines and engineering materials is one of the most interesting aspects of engineering work. It is also of vital importance, because it is only by observing the results of workshop and laboratory tests that the engineer can improve upon the work of his predecessors.

Testing may, therefore, be regarded as the foundation upon which engineering progress is built.

The present book gives a survey of the chief types of works' tests which are employed in connection with the various branches of engineering work.

Chapter I deals with the testing of steam engines, and the interpretation of indicator diagrams. The second chapter is devoted to the testing of engines of the Diesel and semi-Diesel type. In this connection, it may be observed that the same principles may be applied to any type of internal-combustion engine.

As the testing of aero engines is of such outstanding importance at the present time, a special chapter has been devoted to this aspect.

The testing of engineering materials, such as iron, steel, and non-ferrous metals, and also the testing of cements and concretes, form the subject of Chapter IV. Fuel and gas testing and the testing of lubricating fuel oils are dealt with in the concluding chapter.

Whilst it is not claimed that every possible branch of engineering testing has been covered, it is felt that the information given in the following pages will amply meet the everyday requirements of engineers who are concerned with the routine testing of engineering plant and materials, as distinct from the highly specialised work of the testing laboratory.

E. M.

CONTENTS

TEST ENGINEERS' HANDBOOK

Chapter I

STEAM-ENGINE TESTING

THE subject of this book is dealt with in three parts : (1) the testing of engines—steam, oil, and aeroplane engines, in that order ; (2) the testing of materials ; and (3) the testing of fuels and lubricating oils.

The device used for testing steam engines is the steam-engine indicator

The Object of the Indicator

The object of the steam-engine indicator is to provide a diagram showing the steam pressure in the engine cylinder at all positions of the piston. This diagram is of great importance to the engineer as it gives a complete record on paper of the events taking place in the cylinder, and it can therefore be used as a means for ensuring economy in running. This means a saving in steam and coal, low cost of repairs, and an increased life of the engine. Some of the uses to which the indicator diagram is put are given on page 10. First, however, let us consider the instrument itself.

The External Spring Type Indicator

Steam-engine indicators vary in design according to their make and type, but for the purposes of this article it is proposed to consider the external spring indicator shown in Fig. 1.

It consists of a piston and cylinder A connected by means of a cock to a tapped hole in the engine-cylinder wall. An air-cooled calibrated spring B (see also Fig. 3) is fitted to the piston rod so that the travel of the rod is proportional to the steam pressure acting on the piston, and this spring is made specially strong to reduce the piston travel, thus minimising the inertia effect which would otherwise tend to distort the diagram.

To produce a diagram of readable proportions, the piston rod is fitted with a parallel motion C, or link gear, working on the pantograph principle, and reproducing exactly the movements of the piston but on a larger scale. One link D carries a pencil with which the diagram is drawn.

The diagram paper is attached by clips to a reciprocating drum E (see also Fig. 2) which is connected through a stroke-reducing gear—referred to later—to the crosshead of the engine. In this way, every movement of the engine piston is reproduced exactly by an equivalent movement of the indicator drum but on a small scale, the size of diagram obtained being about 4½ in. long and 2¼ in. high.

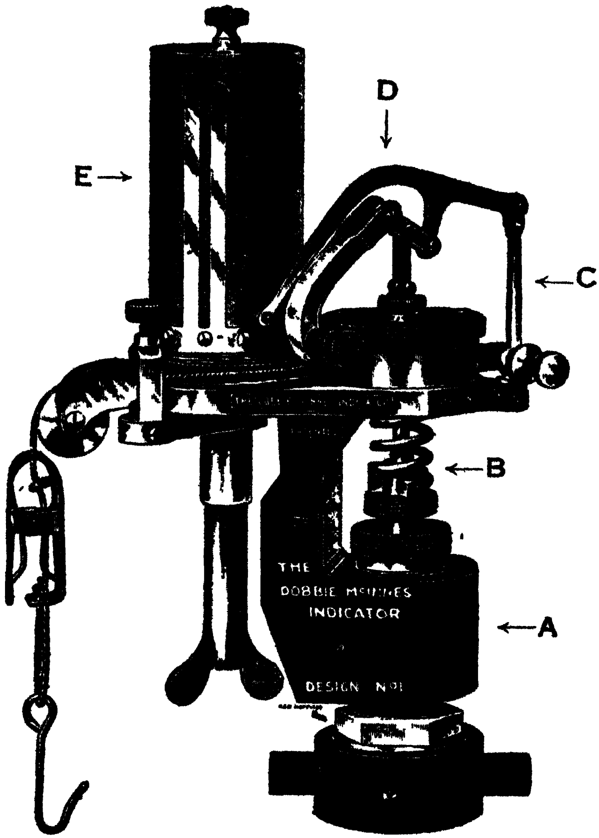


Fig. 1.—The "Dobbie-McInnes" external spring steam-engine indicator

A, piston and cylinder. B, spring. C, link gear. D, link-carrying pencil. E, drum.

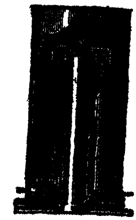


Fig. 2.—Recording drum

Showing the spring for keeping the cord taut and for returning the drum during the back stroke.

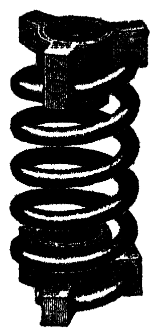


Fig. 3. — Indicator spring marked "40"

Pressure of 40 lb. per sq. in. will raise indicator pencil 1 in.

The indicator cock (Fig. 4) is two-way so that when the indicator is shut to the engine it is automatically opened to atmosphere ; also when the indicator is isolated, the engine or tail pipe is opened to atmosphere to allow for clearing away condensed steam.

The Indicator Reducing Gear

Owing to the importance of using an accurate reducing gear to minimise errors of the diagram in a horizontal direction, illustrations of correct (Figs. 5 to 7) and incorrect gears (Figs. 8 and 9) are shown—some diagrammatically. Fig. 5 shows the "Dobbie-McInnes" "Wade" gear, which is of the differential pulley type. Since the gear is fitted to the indicator, and a cord taken directly from the engine crosshead to the hook

shown on the left of the photograph, this gear is a very convenient one. The lever-type gear (Fig. 6) is frequently used on marine engines and is fitted by the engine builder. Those who know the properties of "similar triangles" can verify that this gear is exact and that the movement of the indicator lead is proportional to that of the crosshead. Another gear having similar properties is shown in Fig. 7.

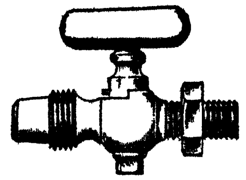


Fig. 4.—INDICATOR COCK

With lock-nut, so that it may be secured in any position.

Points which Apply to All Types of Gear

It is difficult to name any one type of gear that can be used universally, as many factors such as space available, position of indicator relative to crosshead, engine speed, etc., require consideration. The following points should be observed, however, for all types of gear:

1. The stroke reduction should be such that the indicator drum rotates backwards and forwards without reaching either of its two stops.
2. The motion of the indicator lead should always be proportional to that of the engine piston.
3. There must be no play or slackness in the gear.
4. The indicator lead should be taut, as inelastic as possible, and free from kinks.
5. Change-direction pulleys for the lead should be few in number, light, of comparatively large diameter, well lubricated, and not slack.

Preparation for Test

Suppose indicator diagrams are required from a triple expansion marine steam engine. As there are three cylinders, three indicators and three reducing gears are required.

A reducing gear is therefore fitted to each crosshead, and a copper pipe similar to that shown in Fig. 11 is led from the top and bottom of each cylinder to a change-over cock screwed to take the indicator cock. This enables a diagram to be taken of the steam pressures above and below

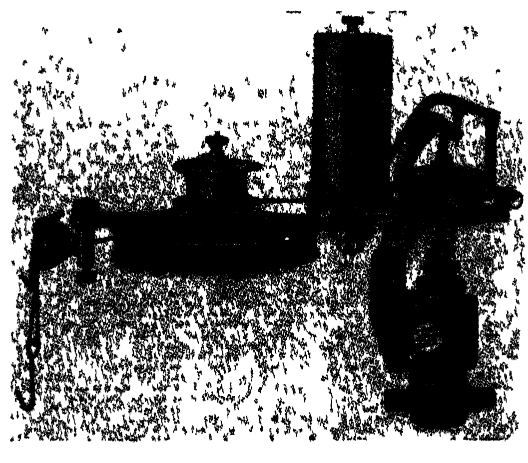


Fig. 5.—THE "DOBBIE-MCINNES"-"WADE" REDUCING GEAR FITTED TO INDICATOR

Cord is taken direct from crosshead to hook shown on left.

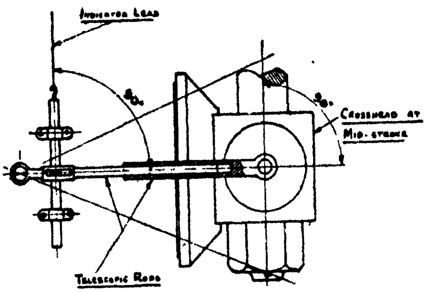


Fig. 6.—Lever-type reducing gear

The above type is frequently used in marine practice and is fitted by the engine builder. The movement of the indicator lead is proportional to that of the crosshead, this type of gear being quite accurate.

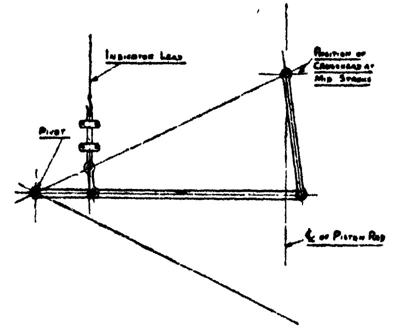


Fig. 7.—Correct reducing gear of lever type

Gear having similar properties to that shown in Fig. 6. Movement of lead is proportional to movement of engine piston. Note the "similar triangles" made by position of the different levers.

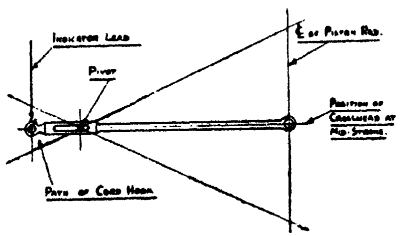


Fig. 8.—Faulty reducing gear of lever type

This type of gear does not give an accurate diagram. The movement of the lead is not proportional to the movement of the engine piston. The path of the cord hook is curved. The use of such a gear should be avoided.

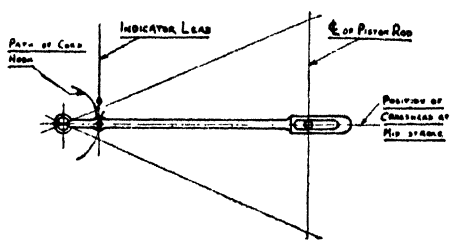


Fig. 9.—Another faulty reducing gear of the lever type

Here again the movement of the lead is not proportional to the movement of the engine piston. Note that the cord hook takes a curved path. It is very important that an accurate reducing gear be used in order to minimise errors of the diagram.

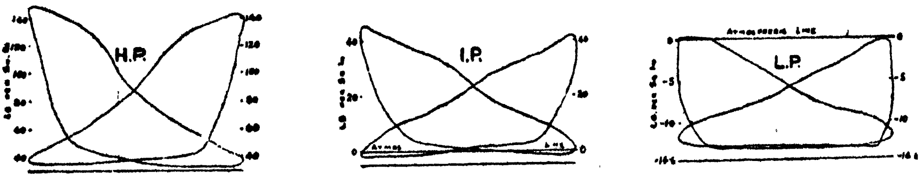


Fig. 10.—Set of diagrams from three cylinders of triple expansion marine engine

The width of the diagrams represents a piston stroke of 39 in., and the strengths of the springs used are indicated by the scales of pressure shown alongside each card, the atmospheric lines representing zero. The atmospheric line is not shown on the high-pressure card, but its position is easily found from the pressure scale.

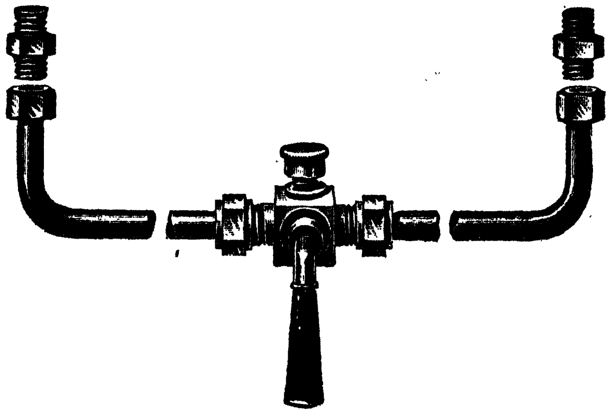


Fig. 11.—CHANGE-OVER COCK AND PIPING

To enable one indicator to be used for top and bottom of cylinder. For vertical engines, the cock is of different pattern.

each of the three pistons of the engine without using six indicators, and the diagram from the top of each cylinder is taken on the same card as that from the bottom and immediately after it.

On screwing the instruments in position and adjusting their drumcord pulleys, indicator cord, which is specially made for the purpose, is stretched from the reducing gears to the drum cords and suitable lengths are chosen so that each diagram shall be positioned midway along the diagram paper.

The indicator pistons are removed, cleaned, and oiled, and each is fitted with a spring of such a strength that the particular maximum pressure will raise the pencil to a point on the diagram paper just below the top stop; this ensures the largest possible diagram being obtained. On reassembling the pistons, the indicators are ready for test.

It might be mentioned here that the strengths of indicator springs are engraved on their heads. Fig. 3 shows a spring of strength 40 which means that a pressure of 40 lb. per square inch on the indicator piston will raise the *pencil* one inch. In the indicator referred to above, such a spring will allow pressures up to 90 lb. per square inch to be recorded, and this figure "90" is also engraved on the spring heads.

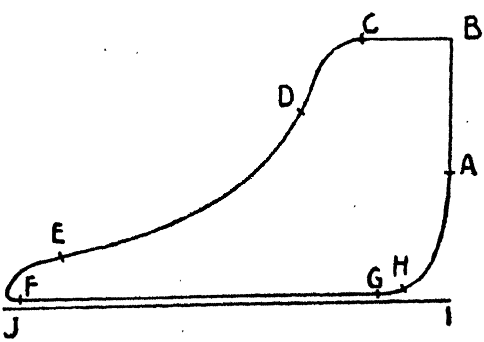


Fig. 12.—TYPICAL STEAM-ENGINE DIAGRAM

AB, admission line. BC, steam line. D, point of cut-off. DE, expansion line. E, point of release. FG, exhaust or back-pressure line. H, point of compression. HA, compression line. IJ, atmospheric line.

For a condensing engine, or for the L.P. cylinder of a triple expansion engine, part of the diagram is

below the atmospheric line, and a special light spring is used to allow for this. The markings of such a spring may be, say, " 10," that is : 10 lb. per square inch for every inch of pencil travel, and " V + 7," that is : it may be used from a vacuum or from pressures below atmospheric up to a maximum of 7 lb./sq. in. above atmospheric.

Taking the Diagram

By means of the indicator cock, the instrument is opened to atmosphere and the pencil is placed against the diagram paper. The drum cord is then pulled by hand to draw the atmospheric line from which pressure measurements are made.

The cock handle is turned so that condensed steam can be cleared from the tail pipe which is afterwards put into communication with the indicator, the pencil meantime being removed from the drum while the cord is hooked to the lead from the gear. A short time is allowed for the steam to warm the indicator, and a diagram is then obtained.

When a branch pipe is used (see Fig. 11), the process is repeated for the other end of the cylinder, thus obtaining a second diagram on the same card, the atmospheric line being common to both outlines.

Fig. 12 illustrates the essential features of a steam-engine diagram. Steam is admitted to the cylinder at A and the pressure rises to B, the piston being on top dead centre. This causes the piston to move to C, steam still entering. At C, the slide valve begins to close, the steam supply being completely cut off at D. From D, the steam expands in the cylinder, driving the piston before it until at E the slide valve opens and allows the steam to escape to exhaust. The piston reaches the bottom centre and during the return stroke pushes the remainder of the spent steam through the exhaust port until at H the slide valve has closed. From H to A, what steam is left in the cylinder is compressed to the pressure at A, when the cycle is repeated.

Uses of the Diagram

The *area* of the diagram which represents the work done during the cycle is used for finding the indicated horse-power (I.H.P.) of the engine, that is : the power delivered by the steam in driving the engine itself and in propelling the ship or the machines to which the engine may be coupled.

The *outline* of the diagram, showing the positions of admission and release, the amount of initial, maximum, and back pressure, and the extent of compression and expansion, gives a good indication of correct or incorrect valve setting which, if incorrect, may seriously increase consumption of steam and fuel without addition to the power output.

Two other valuable calculations, using the indicator diagram, are made to find the efficiency of the engine : one is the determination of the hourly consumption of steam for every I.H.P. developed, and the other that of the mechanical efficiency (B.H.P. ÷ I.H.P.) which shows how much energy is necessary to overcome friction in the engine.

Chapter II

OIL-ENGINE TESTING

NOW that compression ignition engines are being used for motor vehicles, and are being made to run at very high speeds, it is important, so far as indicators are concerned, to distinguish between engines of this type and those running at comparatively slow speeds, such as ships' main engines and auxiliaries and engines used for driving large electric generators. Each type has its own indicator, and the following chapter relates to the low-speed model. We shall now consider indicating, say, a ship's main Diesel engine, the apparatus required consisting of the indicator, indicator valve, and reducing gear, all of which differ from the corresponding units used for steam engines.

The Indicator

Fig. 1 shows a well-known type of Diesel engine indicator, and although it operates on a similar principle to the steam engine indicator, it has a number of features to suit the exacting conditions met with in compression ignition practice. Since cylinder pressures are much higher, the indicator is strengthened throughout, and while double—instead of single—coil springs are used to prevent the use of unnecessarily heavy spring wire, which would unduly stress the instrument, a piston of reduced area is fitted. This means that with the same engine pressure in the indicator cylinder, a spring of only half strength gives the same diagram height with a half-area piston and only half the force is felt by the piston rod. The piston, which is hardened and of heat-resisting steel, has grooves cut in its surface to collect carbon and other grit blown into the indicator cylinder by the engine gases. These channels also accommodate lubricating oil. The recording drum allows for a diagram 2 in. high and 4 in. long.

Other notable points include a double pulley for the cord, and a strong arch for protecting the parallel motion; also the indicator is often fitted with spare cylinders and pistons of still smaller areas and a "detent" gear, so that the drum can be stopped for changing the diagram paper without unhooking the cord.

The Diesel Indicator Valve

When indicating a Diesel engine, it is found that if an ordinary indicator cock is used, seizure of the cock plug takes place owing to the

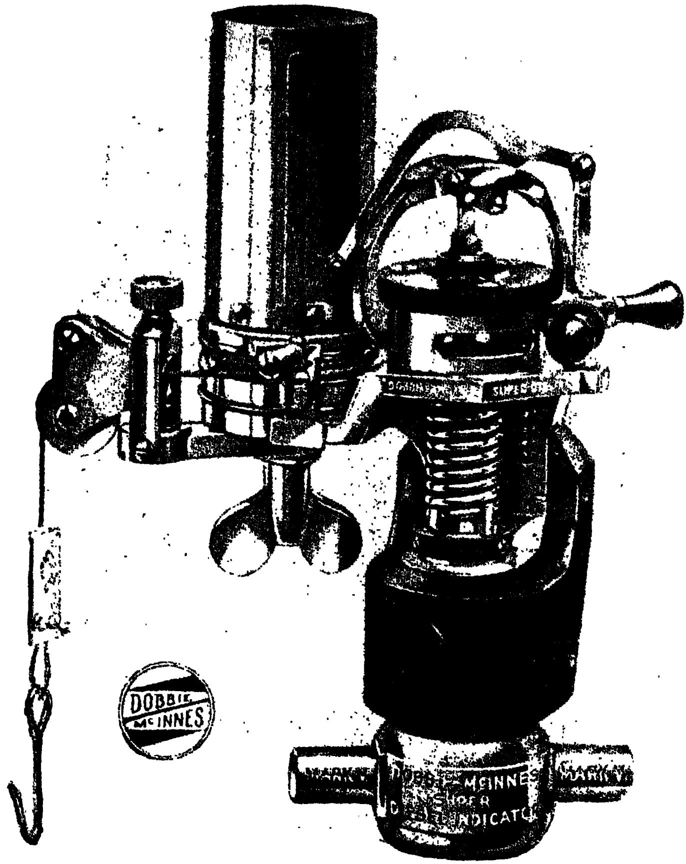


Fig. 1.—" Dobbie-McInnes " diesel engine indicator

intense heat. Therefore a valve is used instead, and it is of special design, so that the indicator can be opened either to atmosphere for taking the atmospheric line or to the engine cylinder. A convenient type of valve is shown in Fig. 2. This has only one handle, is straight through (bends cause diagram inaccuracy), and is double-seated, so that when the engine is isolated, as shown in the illustration, the indicator is open to atmosphere, and when the spindle is screwed outwards the upper seat comes into play, closing the atmospheric hole and opening the indicator to the engine. No stuffing box is required with this valve, and as the spindle is screwed with a " quick " thread, the full movement can be accomplished in under two turns of the handle—more or less a flick of the wrist.

Reducing Gears

Unlike the steam engine, the Diesel has a camshaft which is not far from the indicating points. This shaft is therefore conveniently used for the reducing gears—the contrivances used to actuate each indicator drum so that the movement of the latter shall be a reduced-scale copy of the

motion of the particular engine piston. Before the gears are fitted, it must be remembered that the drums must be pulled forward and backward once while the respective pistons move from top centre to bottom centre and back again; also that the two-cycle engine camshaft rotates once for every revolution of the crankshaft and the four-cycle camshaft only half a turn per crankshaft revolution.

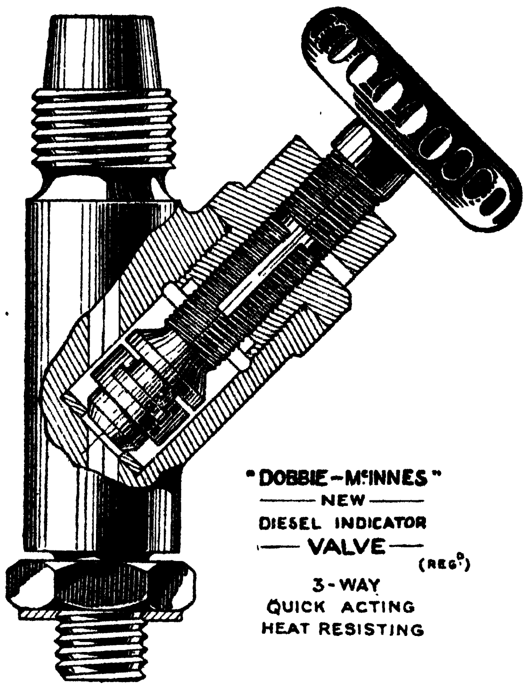


Fig. 2.—"Dobbie-McInnes" diesel indicator valve, shown closed to engine and indicator opened to atmosphere

Fig. 3 illustrates an eccentric type gear often fitted to the camshaft of a two-cycle engine; it will be noted that it is really a small reproduction of the connecting rod and crank of the engine, and to obtain a correct diagram it is important that:

$$\frac{\text{distance a}}{\text{distance b}} = \frac{\text{length of engine connecting rod}}{\text{length of engine crank}}$$

For a four-cycle engine a double-cam gear is frequently used (see Fig. 4).

When constructing this type of gear it is insufficient merely to fit two semicircular cam profiles on opposite sides of the shaft, even though they may be accurately set so that their peaks are under the rocker arm roller when the engine is on top dead centre; the cam profiles must be accurately designed to allow for what is known as the eccentricity of the connecting rod. No allowance need be made for this when fitting a reducing gear to

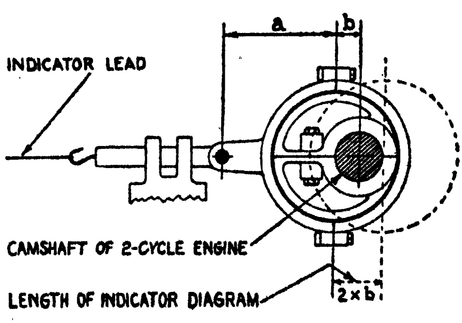


Fig. 3.—Eccentric type gear

a/b must equal engine connecting rod to crank ratio.

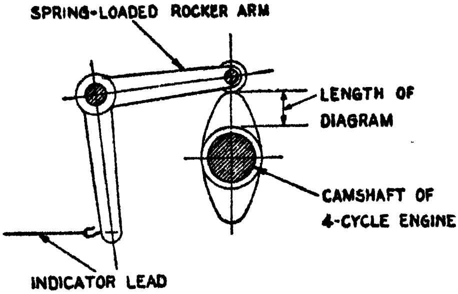


Fig. 4.—Cam type gear
Cam profiles must be accurately designed. Rocker arms shown of equal length.

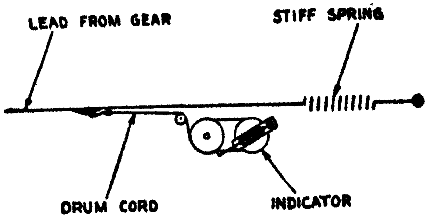


Fig. 5.—Method of connecting indicator
Stiff spring relieves indicator drum spring from necessity of keeping lead taut.

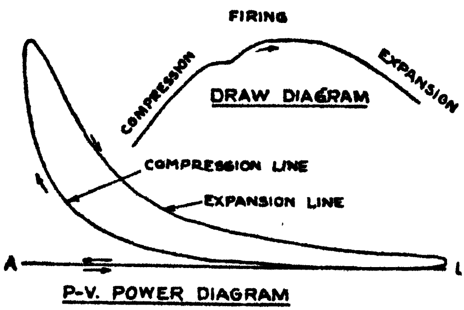


Fig. 6.—Four-cycle engine indicator diagram with hand-operated draw diagram on same card

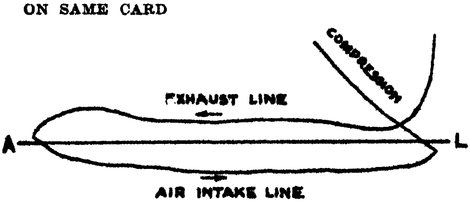


Fig. 7.—Four-cycle engine light spring diagram magnifying the events during the two "idle" strokes

an engine cross head, but we are now dealing with a rotary part between which and the piston the connecting rod and crank intervene.

Connecting up the Reducing Gear

If reducing gears have not been fitted by the engine builders, this must be done in accordance with the above, and the gears must be set so that the points to which the indicator leads are to be attached will move in phase with the respective pistons. Indicators and valves are then screwed into the cylinder tail pipes, which should be of large bore and as straight as possible. A lead made of indicator cord, steel tape, or wire is stretched between the hook or ring on each gear by a strong spring to a fixed pin on the engine, the spring being used to keep the lead taut—see Fig. 5—and the lead should be taken as near to the indicator as possible, with the pin preferably beyond it. A loop is made in the lead or attached to it for the indicator cord hook.

Setting the Drum Cord

Any one piston is put on top centre, at which point the indicator lead will be at the end of its stroke. The drum cord is lengthened or shortened until, when hooked to the loop, the drum is clear of the stop. On slowly turning the engine one revolution, the drum should

rotate forwards and backwards without reaching either stop.

Indicator Spring

After cleaning and oiling the indicator piston, a pressure spring is chosen for the instrument, from a knowledge of the maximum engine pressure, to give the requisite diagram height. On reassembly, the instrument is ready for the test, the drum cord being unhooked, the valve shut to the engine, and a diagram card placed on the drum.

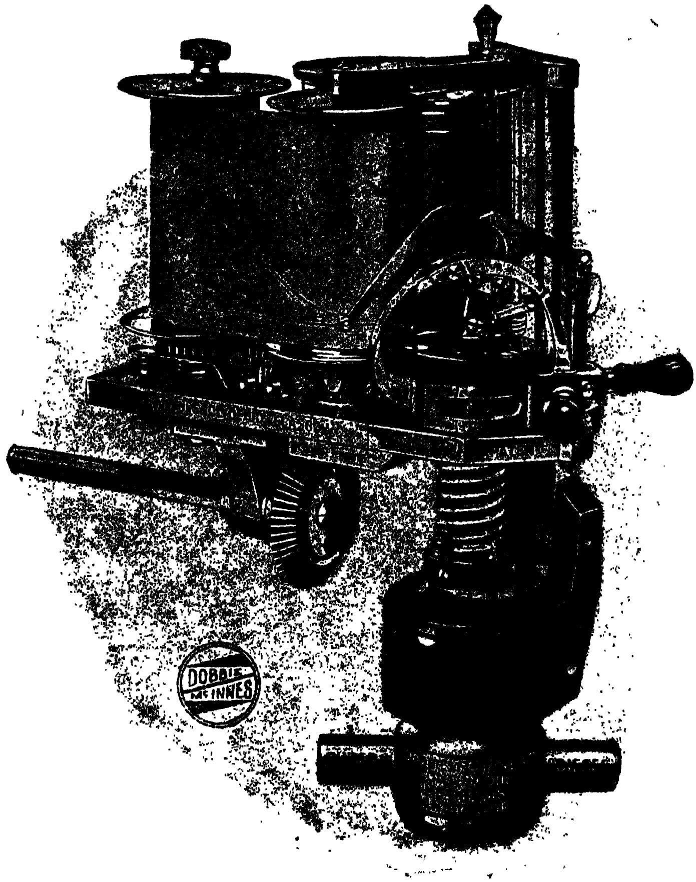


Fig. 8.—" DOBBIE-McINNES " CONTINUOUS TIME BASE DIAGRAM DIESEL INDICATOR
(Diagram can be seen on indicator chart)

The Test

When engine conditions are reached for which indicator diagrams are required, the drum cord is hooked to the loop to set the drum in motion. The valve is opened to the indicator, the pencil of which is lightly put in contact with the paper for one cycle and withdrawn. The valve is shut and the pencil is again applied to draw the atmospheric line. Since there is no condensation to clear away, as in the steam engine, the valve should always be shut, except when actually taking the card.

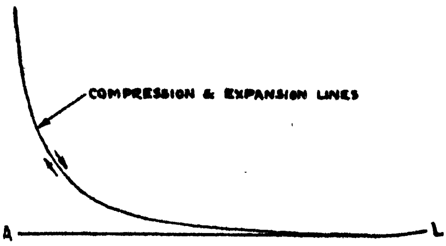


Fig. 9.—COMPRESSION DIAGRAM TAKEN WITH FUEL SHUT-OFF TO CYLINDER BEING INDICATED

DIESEL ENGINE DIAGRAMS

Five important types are shown in Figs. 6 to 11, which are copies of actual diagrams obtained from large six- and eight-cylinder marine engines.

Four-cycle Engine P.V. Power Diagram

Fig. 6 illustrates the type of diagram obtained as described above. It will be noticed that at the peak, where firing takes place, the diagram is very narrow, because the indicator drum is at the end of its travel and is moving very slowly. To investigate what is happening during combustion a draw diagram is taken ; the most important part of this is shown on the right of the pressure-volume diagram, and is obtained by pulling the indicator drum cord by hand as the pencil rises and falls. The point at which firing begins is clearly shown, and the height of the outline at this point gives the compression pressure. AL is the atmospheric line common to both diagrams.

Four-cycle Engine Light Spring Diagram

To examine events during exhaust and intake, it is necessary to magnify the bottom of the diagram which appears in Fig. 6 as straight lines coincident with the atmospheric line. A light spring is therefore fitted to the indicator and the result is shown in Fig. 7.

Crank-angle Base Diagram

Since the shape of the peak of a Diesel diagram is of such importance, means are often provided to give a mechanically operated draw card, so that the diagram has a form similar to the draw diagram shown in Fig. 6, but can be calibrated horizontally as well as vertically. Such a diagram is shown in Fig. 8—the crank-angle base diagram, where

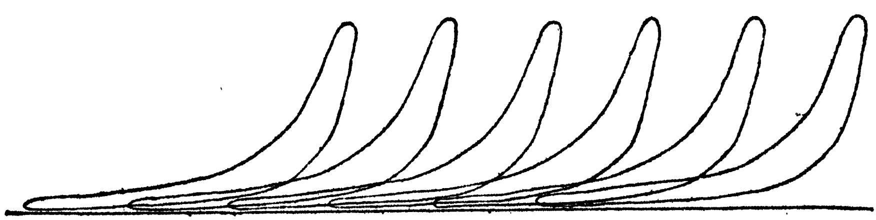


Fig. 10.—DIESEL ENGINE DIAGRAMS FROM CONTINUOUS DIAGRAM INDICATOR

Horizontal line at bottom is drawn by a second pencil and may be made coincident with atmospheric line as shown in Fig. 11. Engine running on full load.

horizontal measurements represent not piston stroke or volume, but degrees turned through by the crankshaft. It is obtained on a continuous roll of paper driven by a spindle coupled to the camshaft, the special instrument used being the "Dobbie-McInnes" continuous time-base diagram Diesel indicator.

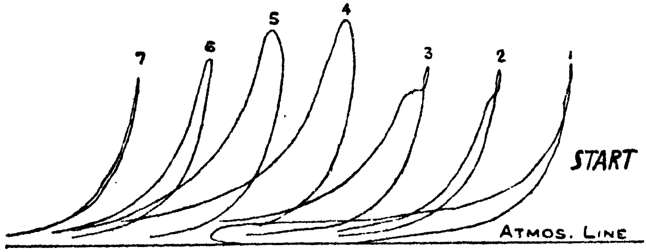


Fig. 11.—DIESEL ENGINE DIAGRAMS FROM CONTINUOUS DIAGRAM INDICATOR, TAKEN DURING STARTING AND STOPPING

1. Air impulse (pressure carried nearly full length of stroke). 2. Firing lightly. 3. Firing (ignition late). 4. Firing heavily (handles hard over). 5. Full power (fuel being shut off). 6. Fuel being shut off. 7. Fuel off (almost a compression card—engine nearly stopped).

Compression Diagram

This is obtained by shutting off the fuel from the cylinder being indicated and is used to test the setting and accuracy of the indicator gear. Its correct shape is as shown in Fig. 9, with compression and expansion lines apparently coincident. Should it be looped, the gear requires adjustment.

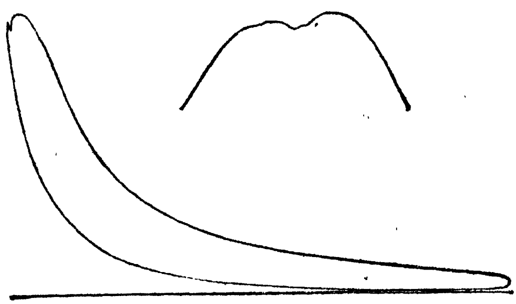


Fig. 12.—DIAGRAM SHOWING LATE FUEL INJECTION

Compare with Fig. 6.

Continuous Diagrams

It is sometimes of value to study changes in the form of the diagram under varying conditions. For this purpose the continuous-diagram indicator is used and gives a complete record of consecutive diagrams on the same paper. A roll of paper is

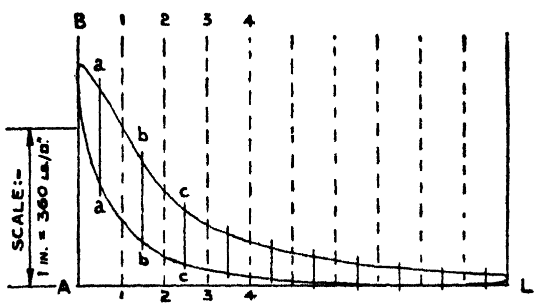


Fig. 13.—THE "MEAN ORDINATE" METHOD OF MEASURING UP THE DIAGRAM FOR CALCULATION OF M.I.P. AND I.H.P.

(M.I.P. of this diagram is 90 lb. per sq. in.)

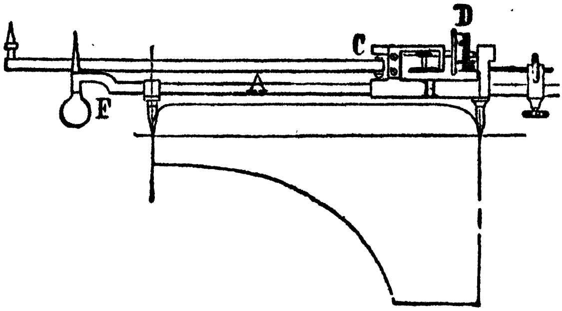


Fig. 14.—Setting the No. 6 planimeter to the diagram width

used, which is wound from a spindle inside the drum round the periphery of the drum and back to a second internal spindle. Movement of the paper with respect to the drum occurs automatically during the intake or exhaust stroke, and therefore does not interfere with the form of the diagram, which is the normal p.v. diagram repeated. Fig. 10 shows continuous diagrams from a four-cycle Diesel engine running at full load. Fig. 11 illustrates the pressure and power changes while the engine starts up and stops. It should be noted that Figs. 10 and 11 are tracings of the originals, and that in Fig. 11 the toes of diagrams 2 to 7 have been omitted, as in this particular test only the peaks were under consideration.

Engine Faults

To obtain maximum economy in running, and to ensure there are no undue strains on the engine, it is essential that valves should open and close at the correct points of the cycle and that combustion should be even. Valve setting is checked by examination of the indicator diagram, which also shows such faults as choked atomisers, early or late firing, over- and under-loading of the engine. Fig. 12 shows an example of late firing. Note the dip at the top of the draw card and the low maximum pressure as compared with the compression pressure; such conditions prevent the particular cylinder from giving full power and efficiency.

MEASUREMENT OF M.I.P. AND I.H.P.

The mean indicated pressure, sometimes called indicated mean effective pressure—I.M.E.P.—can be found by the planimeter, an instrument for measuring areas, or by the following simple method:

Referring to Fig. 13, draw a straight line perpendicular to the atmospheric line AL at each end of the diagram AB and LM and divide the distance between the perpendiculars into 10 equal parts, A-1, 1-2, 2-3, etc. At the midpoint of each division draw 10 straight lines, *aa*, *bb*, *cc*, etc., also perpendicular to the atmospheric line. Find the total length of those parts of *aa*, *bb*, *cc*, etc., contained by the diagram, multiply by the pressure scale of the diagram, and, by dividing by 10, average the result to give the required mean pressure. For example, if the total length of the "mean ordinates" were found to be 2·50 in., and the

indicator spring scale was 360 lb./sq. in. per inch, then:

$$\text{M.I.P.} = \frac{2{\cdot}50 \times 360}{10}$$
$$= 90 \text{ lb./sq. in.}$$

I.H.P. is obtained from the M.I.P. thus found by multiplying it by the product of the stroke in *feet* L, the cylinder area in *square inches* A and the number of *working strokes* per minute N, dividing the result by 33,000, i.e.:

$$\text{I.H.P.} = \frac{\text{M.I.P.} \times \text{L} \times \text{A} \times \text{N}}{33{,}000}$$
per cylinder.

For a two-cycle engine N is the same as the number of revolutions per minute; for a four-cycle engine N is half the r.p.m., as there is only one working stroke every two revolutions.

Use of the Planimeter

The above method of determining M.I.P., while frequently used, is not as accurate theoretically as one which enables the diagram area to be determined, thus eliminating calculation by mid-ordinates. The "Amsler" No. 6 planimeter shown in Figs. 14 and 15 measures the actual area of the diagram, and it has, in addition, an arrangement for finding the mean height.

Thus, a small variation at the peak of the card, which would not be taken into account by the mid-ordinate method, would be shown in the result obtained by the planimeter.

The diagram card is pinned to a drawing-board, and, as shown in Fig. 14, the planimeter is reversed.

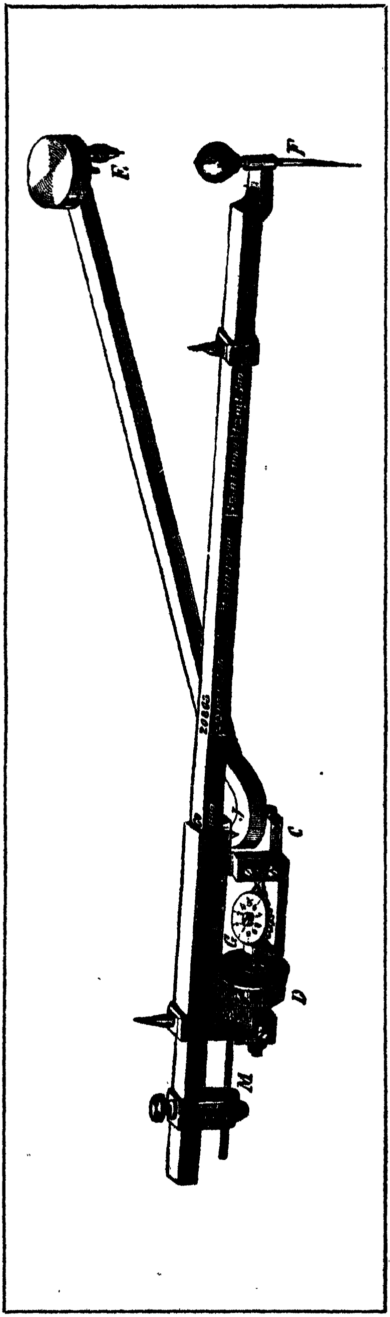


Fig. 15.—"Dobbie-McInnes" "Amsler" No. 6 Planimeter for measuring M.I.P. and I.H.P indicator diagrams

By moving the slide on the tracing arm, the planimeter is set so that the distance between the points on the upper side of the arm is equal to the width of the diagram. Without altering this distance, the planimeter, Fig. 15, is placed on the board in a convenient position with the needle point E outside the diagram and the pointer F resting on the outline of the diagram. An initial reading is taken on the dials G and D. Without disturbing E, the pointer F is carefully traced round the diagram, following every feature of the curve until one complete circuit is made. The final reading is taken, and the initial reading subtracted from it. Dividing the result by 0·4 gives the mean height in inches, which, when multiplied by the scale of the indicator spring, gives the M.I.P. from which I.H.P. is found in the usual way.

Example:

Second reading of Planimeter	1·784
First reading of Planimeter	1·682
Difference	0·102
Divide by 0·4	0·255 in. Mean Height.

If scale of spring is 360 lb./sq. in. per inch,

$$\text{M.I.P.} = 0{\cdot}255 \times 360$$
$$= 91{\cdot}8 \text{ lb./sq. in.}$$

It is now an easy matter to calculate the indicated horse-power of the engine by using the formula $\text{I.H.P.} = \frac{\text{M.I.P.} \times \text{L} \times \text{A} \times \text{N}}{33{,}000}$, bearing in mind that the formula gives the horse-power of one cylinder only. The total I.H.P. of a 4-cylinder engine, for example, would be four times the value given by the formula.

Chapter III

TESTING AERO ENGINES

IT is not intended in this chapter to deal with the complicated and extensive testing carried out on a new engine during its development, but rather to commence at the period when it is considered that its performance has reached a sufficiently high standard that it may be submitted to an official type test. Since all modern high-performance engines are supercharged in some form or other, it is intended to refer particularly to this type. It is also intended to describe the endurance and final tests constituting the acceptance tests of a series engine.

The decision to carry out an official type test is made only after very careful consideration of the engine's power output at various engine speeds and blower delivery pressures both under ground-level and altitude conditions. Its reliability at climbing and economical cruising speeds and boosts must be such that a life of 400 to 500 hours between overhauls may be reasonably expected under actual service conditions. A very high standard of consistency in starting under cold and warm atmospheric conditions must have been attained and the slow running and acceleration must have given entire satisfaction under every conceivable condition likely to be attained in service.

Testing a radial air-cooled engine has been taken as a typical example in this chapter.

Rating of the Engine

During the experimental development of the engine a series of performance curves are completed at various r.p.m., ranging from 20 per cent. below normal to 20 per cent. above, at various blower delivery pressures. These curves are termed constant boost curves, and are carried out at various fuel consumptions from which suitable tuning figures are decided.

The boost pressures for the desired sea-level ratings at take-off, maximum climb, and maximum cruising conditions are decided from these results, and even the altitude at which rated boost is attained is determined by bench test.

In Fig. 1 the complete "family" of curves for preparing the main items of the engine rating is shown. The data are taken from results on the Bristol Mercury VIII, which is a fully supercharged engine with an official all-out level performance of 840 b.h.p. at 2,750 r.p.m. at 14,000 ft., and an international rating of 795/825 b.h.p. at 2,650 r.p.m. at 13,000 ft.

Curve *ab* represents the power output at various r.p.m. at maximum cruising boost at sea-level and indicates the limiting performance available at speeds not exceeding maximum cruising r.p.m. for continuous level

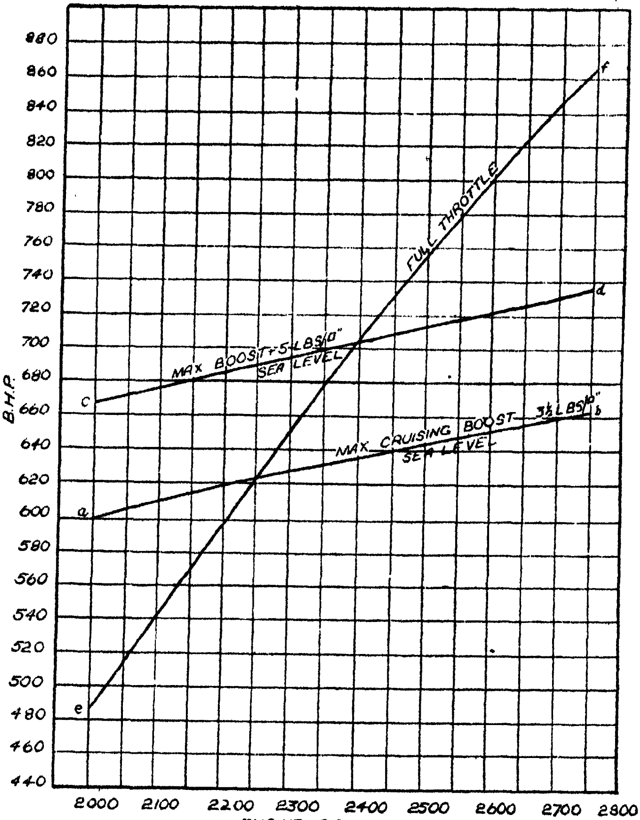


Fig. 1.—CONSTANT BOOST AND ALTITUDE CURVES FOR MERCURY VIII

flight. At speeds above maximum cruising r.p.m. the power is available for periods of 5 minutes in level flight.

The higher power output constant boost curve *cd* denotes the performance available at sea-level for climbing at maximum boost. At this condition the limiting speed is the international r.p.m. which for the Mercury VIII engine is 10 per cent. above the maximum cruising r.p.m. The engine may be climbed at this speed for any desired time, there being no limiting period of 5 minutes so long as the aeroplane is climbing.

In the case of the Mercury VIII the maximum climbing boost is also the maximum take-off boost. It is not essential that these two boosts should be the same, for on moderately supercharged types a further increment in boost is used for take-off, and for some engines this is the maximum blower delivery pressure available with the throttle fully open.

The maximum boost is also available on the majority of engines for all-out level flying, usually up to a speed of 15 per cent. above the maximum cruising r.p.m. For the Mercury VIII this speed is 2,750 r.p.m., and it is available for short bursts of not more than 5 minutes' duration. This limiting period of 5 minutes is an Air Ministry requirement which must be adhered to in service.

The third curve *ef* is based on the power output of the engine if run at full throttle at all speeds at the international rated height. The boost pressures on the curve vary with the r.p.m., for whereas the

curves mentioned in the previous paragraphs are taken with varied throttle openings and constant boost, the latter curve is taken with fixed throttle opening with the boost pressures varying with the volumetric efficiency of the cylinders and the efficiency of the blower at the various engine speeds.

From this "family" of curves the performance data shown in Fig. 2 is prepared. This indicates the power available on the Mercury VIII at cruising, climbing, and all-out level conditions at various speeds and altitudes. The straight lines indicate the power available at constant boost, gradually increasing with altitude due to the lower temperature and exhaust back pressure, and the curved lines show the fall-off in power experienced with increase in altitude once the full throttle position has been reached.

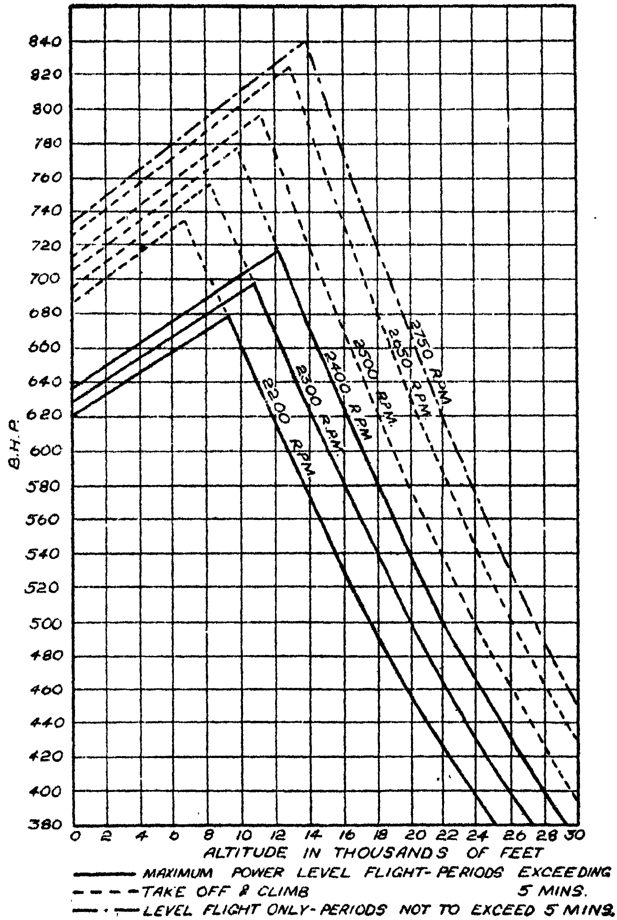


Fig. 2.—Engine performance at altitude for Mercury VII, VIII, and IX

Based on results shown in Fig. 1.

From curves similar to those shown in Figs. 1 and 2, the necessary information required for the preparation of a "Declaration of Type Test," which must be sent to the Air Ministry before the test commences, can be obtained.

Definitions

The reader may not be familiar with the various terms employed in defining the rating and the following explanation will be of assistance.

1. When rating an engine the declared maximum climbing r.p.m. is the international r.p.m.

2. The maximum climbing boost is the international or rated boost.

3. The rated altitude of the engine is the lowest height at which full throttle is permissible at the international r.p.m. and is also the highest altitude at which the international or rated boost can be maintained at the international r.p.m.

4. The rated power is the corrected b.h.p. attained at the rated altitude at the international r.p.m.

5. The maximum cruising boost is the maximum boost available for continuous level flying. The corrected sea-level power at this boost may not be less than 90 per cent. of the power at sea-level at the maximum boost pressure for level flight at the maximum cruising r.p.m.

6. The maximum climbing boost must not exceed the maximum boost for level flight, but the maximum boost for take-off may be higher than the climbing boost. In actual service the use of a take-off boost higher than the climbing boost is limited to a duration of three minutes or until a height of about 1,000 ft. is reached.

7. The international or maximum climbing r.p.m. is the highest crankshaft r.p.m. that may be maintained continuously for periods exceeding 5 minutes' duration.

8. The maximum r.p.m. for level flight is the number of crankshaft r.p.m. which must not be exceeded, excepting momentarily during a dive or aerobatic, or maintained for periods exceeding 5 minutes.

9. The maximum r.p.m. for continuous cruising may not be greater than 50 r.p.m. below the maximum for all-out level flight, but must not be less than 85 per cent. of the maximum for level flight.

10. The maximum take-off r.p.m. are declared by the engine constructor. In the majority of instances where V.P. airscrews are fitted this is 10 or 15 per cent. above the maximum cruising r.p.m., but may be even higher.

The minimum r.p.m. for take-off is declared by the engine constructor, but for type test conditions the endurance portion of the test to clear the use of fixed pitch airscrews the r.p.m. are determined from the formula :

$$\text{r.p.m.} = 0{\cdot}95 \sqrt[3]{\frac{a}{b}}\,\text{N}.$$

Where N $=$ 0·87 of the maximum r.p.m. for level flight.

a $=$ b.h.p. at maximum take-off boost at N r.p.m.

b $=$ calculated equivalent full throttle b.h.p. at sea-level at N r.p.m.

Preliminary Tests

Running-in. When the constructor is satisfied that the engine fulfils all the rating conditions, preparations are made for the type test. When-

Fig. 3.—Typical running-in stand

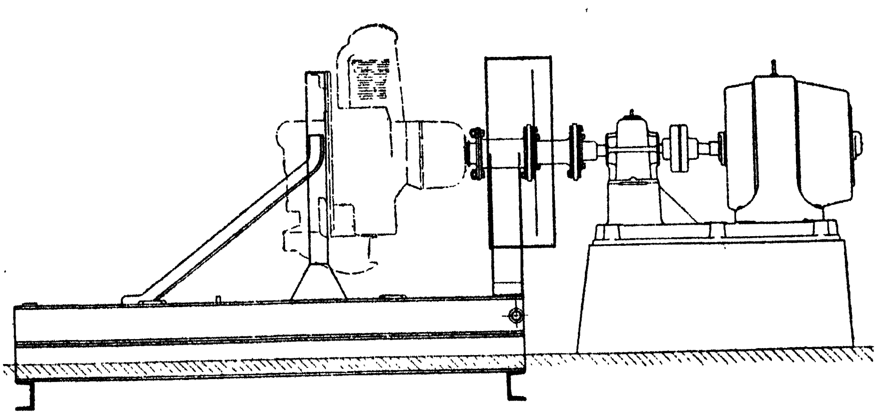


Fig. 3a.—Diagram of running-in stand

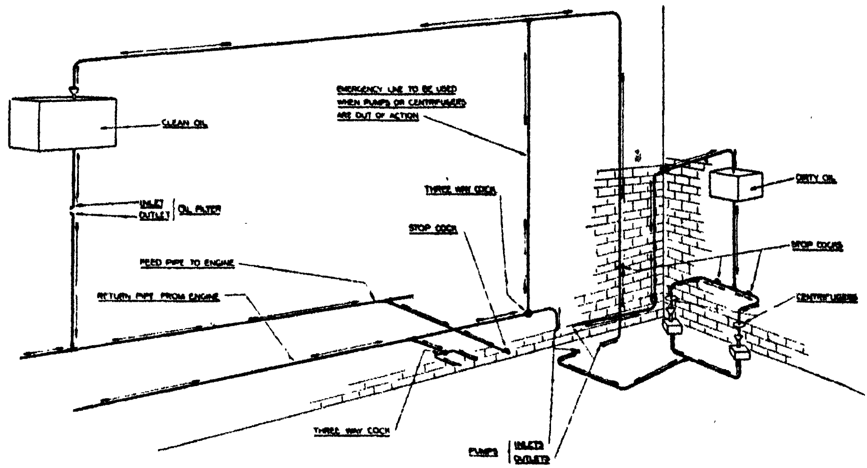


Fig. 4.—DIAGRAM OF RUNNING-IN SHOP OIL-PIPE LINES

ever possible a new engine is allocated similar in all respects to the one which has been used for the development test.

During the erection of the engine the various components are liberally lubricated with oil, and although every precaution is taken to exclude dust and other foreign matter it is considered advisable to run it in for five hours, and during this period it is copiously supplied with oil which is being continually centrifuged.

The running-in stand is of the type shown in Fig. 3. The electric motors are capable of developing 30 h.p., and rotate at 1,500 r.p.m., but the speed of the engine airscrew shaft is reduced to 450–500 r.p.m., by means of an epicycle-reduction gear. The centre line of the engine is not in the same vertical plane as the electric motor shaft.

No sparking plugs are fitted to the engine, and in their places are fitted suitable blanks with wire gauze covers. Consequently while the engine is being run-in, there is little or no compression, and therefore very little heat generated. A fan, however, is attached to the flexible coupling flange on the shafting driving the airscrew shaft. This fan is quite capable of dealing with the small amount of heat generated, and also assists in blowing away the oil vapour as it leaves the exhaust snouts.

Fig. 4 shows diagrammatically the oil pipe lines of a "running-in" shop. The oil is stored in the large gravity tank fitted with electric heater elements and is led to the pressure pump as indicated by the arrows. The used oil is drawn from the engine sump by the engine's own scavenge pump and delivered to the return pipe line. The oil is taken from this line by an independently driven pump and delivered to a small header tank from which it is fed to a series of centrifugers. After being purified

it is returned to the large gravity tank by a second independent auxiliary pump. This completes its circuit.

Endurance Test. After being run in for 5 hours with the oil inlet at about 50° C. and the pressure 80 lb./sq. in., the engine is transferred to a dynamometer test stand. It could, of course, be arranged for the engine to be run-in on the dynamometer, but this is rather an elaborate plant for such a task and would prove very uneconomical.

The most common form of dynamometer in use in England is the Heenan & Froude DPX. A sectional drawing of the layout of this type of dynamometer is shown in Fig. 5.

It is necessary when testing air-cooled engines to conduct the cooling air from a fan *via* a tunnel to keep the cylinder and crankcase temperatures within reasonable limits, compatible with those attained in actual service. The fan is of the centrifugal type driven by a 550-h.p. D.C. electric motor and the tunnel is approximately 5 ft. in diameter. As will be seen from the diagram, the tunnel is led over the brake itself down to the engine mounting. The front or outlet portion consists of a canvas extension supported on metal framework which can be moved backward or forward to facilitate the fitting of the flexible coupling, which connects the airscrew shaft to the dynamometer shaft, for the latter passes through the tunnel to the brake.

The fan is capable of supplying wind speed of 170 m.p.h. over the engine, but for general testing only 110–120 m.p.h. is used. For low wind speeds, say below 70 m.p.h., not attainable by adjustment of the motor resistance, a shutter or damper is fitted in the tunnel with the aid of which the cooling air supply can be restricted.

Erection of Engine on the Dynamometer

The erection of the engine on the dynamometer can be accomplished in a very short time as it is attached to a temporary steel mounting plate when it is built in the shops, and this plate is secured to the test cradle by only four studs and nuts. The cradle is mounted on a trunnion at the rear end and is supported on large steel rollers at the front. The front of the cradle is spring loaded to allow the cradle to give a little on starting and for sudden changes in speed, thus avoiding undue stressing.

While one tester prepares the various oil inlet, scavenge, return, and by-pass pipes and the various gauge connections, another prepares the airscrew shaft for the flexible coupling connection. The splines of the shaft are first smeared with a graphite grease mixture and a flanged hollow shaft having internal splines is then secured in its correct position, which is indicated by the master spline having a greater width than the others. The flange is then secured to the flexible coupling flange by six bolts, the two flanges being brought together by moving the engine and test cradle bodily with the aid of a hand-operated ratchet fitted to the

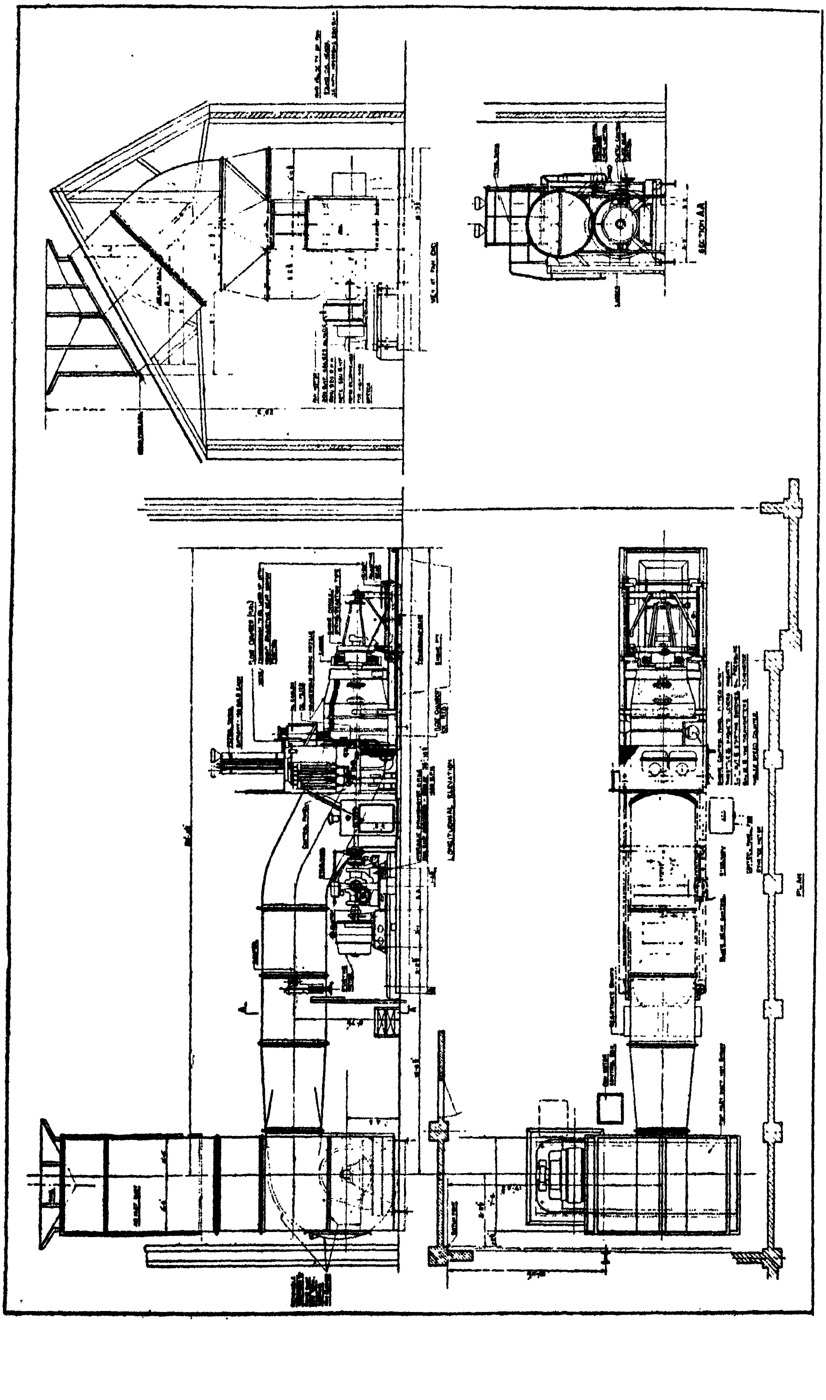


Fig. 5.—GENERAL ARRANGEMENT OF AERO ENGINE TEST PLANT

bed of the cradle which operates a toothed wheel working on a rack on the side of the dynamometer foundation girders.

The various pipes, such as the oil inlet, scavenge, return, and by-pass, the inlet and outlet petrol pipes from an auxiliary tank to the petrol pump and the fuel supply pipe from the flowmeters to the carburettor are then connected. The gauges on the instrument board recording such items as the oil pressure, oil inlet, outlet and sump temperatures, air intake temperature, blower delivery pressure, engine crankshaft r.p.m. are linked up to their appropriate positions.

The stand controls for the throttle and mixture strength are made universally adjustable so as to be adaptable to the various angular movements required on the different types of engines being produced. The controls are operated by levers on the instrument board *via* hollow steel tubes.

Finally the ignition leads to the two magnetos are connected to the two switches and the engine is primed with 1 quart of hot mineral oil *via* the oil-pressure connection with the aid of an auxiliary hand pump attached to the test cradle.

Preliminary Operation by Electric Motor

Before the engine is run under its own power it is motored over for a quarter of an hour by means of an electric motor, the shaft of which engages with the main dynamometer shaft *via* a dog clutch. This motor is also used for starting, the clutch being automatically thrown out of operation as soon as the engine airscrew-shaft speed is greater than that of the electric motor.

The Engine is best run in under Light Load

On the completion of the quarter of an hour the flowmeters are turned on and the engine switched on and run under light load and low speed, say about 800 engine r.p.m. for a period of one hour. During this period some slight alteration to the slow-running adjustment screws may be necessary. This, of course, is only a preliminary adjustment, and can be gauged quite satisfactorily by observation of the exhaust flame which should be light blue in colour.

Endurance Test Condition

The next stage is a period of half an hour during which the brake load and engine speed are gradually increased until the endurance test condition is reached. The endurance test is commenced in the presence of the firm's own inspector, and in the case of engines for the Air Ministry, a representative of the A.I.D.

The oil-inlet temperature is maintained at 70° C. with a tolerance of — 5° C., throughout the endurance test and forms the basic condition on which the oil consumption and circulation are determined. The

temperature of the oil is controlled by means of electric-heater elements and cold-water circulating pipes fitted in the oil tank.

Reading of all Gauges are now Taken

As soon as the endurance commences the readings of the various gauges previously mentioned are recorded, together with the reading of the amount of oil in the tank. Relevant data such as the barometric pressure and atmospheric temperature are also logged. All readings are logged once every quarter of an hour, but of course the instruments are under continual observation throughout the test.

The endurance test is run at maximum cruising boost and maximum cruising r.p.m. For the Mercury VIII these conditions are + 2½ lb./sq. in. and 2,400 r.p.m., the engine developing approximately 635 b.h.p. The boost pressure is measured by means of a mercury " U " tube, one end of which is open to atmospheric pressure and the other connected to the blower casing at a point near the periphery of the diffuser blades. At the top of this latter limb is fitted a small cylindrical copper vessel which acts as a trap and prevents any mercury being drawn into the engine under large depressions.

Setting the Boost Control

It is important when setting the boost control to take into consideration the barometric pressure at the time of the test, for the engine is to be run at a correct boost pressure. For example, the 2½ lb. cruising boost pressure of the Mercury VIII would be represented by 5·1 in. of mercury (1 lb./sq. in. = 2·04 in. Hg.) only if the barometric pressure was standard. If, however, the barometric pressure was 29·35 in. Hg., then the following preliminary calculation would have to be made :

	Standard barometric pressure	= 29·92 in. Hg.
	Boost pressure, 2½ lb.	= 5·1 ,, ,,
	Absolute pressure required	= 35·02 ,, ,,
	Actual barometric pressure	= 29·35 ,, ,,
∴	Required pressure to be recorded on mercury "U" tube	= 5·67 ,, ,,

Oil-consumption Limits

The oil-consumption limits on the Mercury VIII are 6–12 pints/hour, and all engines must have a consumption within this figure during the second half of the two-hour endurance test. On the completion of the second hour a further 5 minutes is run at the international r.p.m., *i.e.*, maximum climbing speed and maximum climbing boost. For the Mercury VIII this condition is 2,650 r.p.m. and + 5 lb. boost. The boost is automatically increased by moving the mixture-control lever into the

over-ride position. This operates a cam in contact with the boost-control diaphragm mechanism and at the same time increases the fuel consumption to prevent detonation at the increased boost. The maximum boost is adjusted by lengthening or shortening the operating rod from the mixture control to the cam mechanism. This rod has left- and right-hand threaded ends for this purpose.

Checking Boost Control

Usually one or two intentional backfires are produced with the boost control set correctly to give the required cruising boost, to ensure that the boost control has definitely settled down. The boost pressure is rechecked after each backfire and if any variation is observed the boost control is reset and the procedure repeated.

Completion of the Test

This concludes the first running period of the engine's life, but before it is removed from the stand the sump filter is removed for examination and a careful inspection is made for oil leaks. All items which require attention are entered on a card which accompanies the engine all the time it is in the works and which serves as a brief synopsis of its test history.

On being returned to the shop, the engine is entirely stripped down and the components laid out on tables for a rigid inspection. It is outside the scope of this chapter to deal with the procedure adopted in the erecting and stripping shops, or to describe the many and varied types of apparatus employed. If, however, all parts are found to be in a satisfactory condition the main components of a type test engine are carefully dimensionally checked for record purposes and for comparison with the strip condition at the end of the test.

Final Acceptance Test

When received by the Test Department, the engine is erected on a dynamometer and is motored over for a period of a quarter-hour after being primed with hot oil as on the endurance test. For a further period of a quarter-hour it is run at low load and speed followed by a third and similar period during which the load and speed are gradually increased to the maximum cruising conditions.

With the brake locked at this condition the throttle is then closed to bring the engine speed down to slow-running conditions and the fuel-air mixture is adjusted to give even and consistent running. The brake and throttle are then set to a predetermined cruising figure at which the fuel-power jet should be just out of operation. This is checked by fitting a blank power jet and noting the fuel consumption and then replacing the correct jet. If any increase in fuel consumption occurs, the cam operating the power-jet valve is adjusted to lift the valve at a slightly larger throttle opening.

With a slight increase of, say, 20 h.p., the power jet just comes into operation and serves to correct the tendency of the main jets to weaken off the fuel consumption. The valve controlling the fuel supply to the power jet has a very gradual tapered seat, and since the cam operating the valve is fixed to the carburettor throttle layshaft further advance of the throttle lever depresses the valve still further and increases the fuel consumption gradually with the increase in power until at maximum cruising boost the power jet becomes the controlling factor and is calibrated to give the desired consumption.

The carburettor layshaft throttle lever is now in its fully advanced position and the actual throttle butterfly position is controlled by the boost control. A further increase in power is attained, however, by moving the mixture control into the over-ride position ; this brings into operation an enrichment jet which is calibrated to give the desired fuel consumption at maximum boost.

The fuel consumption is therefore checked at five points: (*a*) slow running, (*b*) low cruising power, power jet just out, (*c*) power jet just in, (*d*) maximum cruising power, jet fully in, (*e*) maximum boost enrichment jet in operation.

The half-hour final test is run at the same conditions as the endurance test, namely, maximum cruising boost and r.p.m., and similar readings to those already enumerated are recorded.

Throttle Opening and Mixture-control Units are Next Checked

On the completion of the half-hour the units controlling the throttle opening and the mixture are checked for correct functioning. When the boost control was first introduced on Bristol engines the boost setting was a negative value of approximately – 1 lb./sq. in., and if the connecting pipe from the blower volute to the boost-control diaphragm casing broke while an aeroplane was flying at low altitude then atmospheric pressure would be admitted to the diaphragm chamber. This pressure might be higher than the original setting of the control, with the result that the throttle would tend to close, even though the pilot's cockpit throttle lever was fully open.

In order to prevent this rare failure from causing a forced landing due to lack of engine power, a stop was fitted to the boost-control piston which prevented the throttle from being completely shut when the cockpit throttle was fully open. Modern engines are of course set at much higher blower delivery pressure, and a fracture of the boost pipe would admit a lower pressure than the pressure at which the boost control was set and the throttle would tend to open still further, which of course the pilot could counteract by " throttling back."

However, this stop has been retained as a safeguard, and ensures that the pilot will always have sufficient power to maintain height in the event of a failure of any description of the boost control. On the

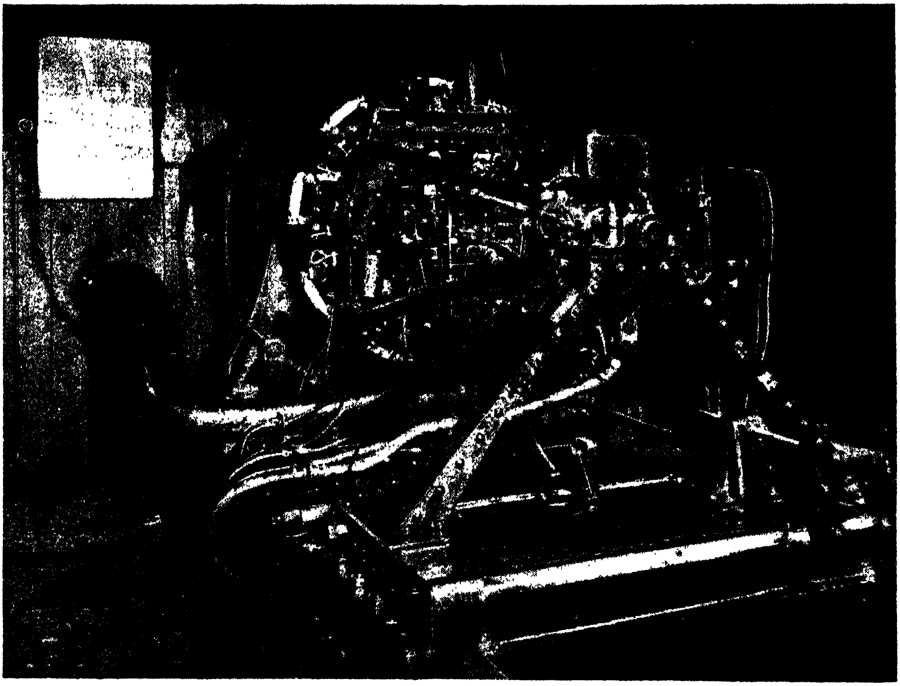


Fig. 6.—ENGINE ON TEST FOR ALTITUDE CURVE

Mercury VIII engines the length of the stop ensures a power of 350 h.p. always being available.

Minimum Power on all Engines is now Checked

This minimum power is checked on all engines and is accomplished by screwing back the diaphragm-adjusting screw to almost its full extent or, in other words, setting the boost control to an extremely low boost. The carburettor throttle layshaft lever is advanced to its full open position, the boost-control piston travels to the bottom of its travel in attempting to close the throttle. The travel, however, is limited by the stop and the power output is noted at normal r.p.m., and if too low a longer stop is fitted.

Checking the Range of the Mixture Control

The range of the mixture control is checked by noting the percentage reduction in the fuel consumption when the control is moved from the normal to the fully weak setting with the engine running at maximum cruising r.p.m. and boost. Obviously the engine cannot run at the full weak position under sea-level conditions, so an auxiliary fuel supply is

fed into the air intake. While the mixture control is operated gradually towards the weak position the auxiliary supply is increased so that the total fuel consumption is maintained constant although the amount passing through the carburettor via the flowmeters gets less and less. From the difference of the readings of the flowmeters in the normal and weak positions the percentage mixture control can be deduced. The minimum range accepted by the Air Ministry is 40 per cent.

Type Test

Initial Performance Curves. Prior to commencing the endurance portion of the type test, a series of constant-boost curves, a throttle-consumption curve, and a full-throttle altitude curve are completed.

The constant-boost curves are required to be completed at maximum cruising, maximum climbing, and maximum take-off boosts. The carburettor layshaft lever is set to give the maximum cruising boost and remains locked in this position while the r.p.m. are varied over a range of speeds from 15 per cent. above the maximum cruising r.p.m. Readings are taken of load, fuel consumption, and cylinder temperatures, etc., at approximately every 100 r.p.m., both down and up the curve. The mixture control is set in the normal position throughout the curve.

Maximum Climbing Boost

On engines like the Mercury VIII the maximum climbing boost is the same as the take-off boost, therefore one curve serves for the two conditions. The mixture control for this curve is in the rich position, the change-over being automatically accomplished when the boost control is moved to the maximum boost position. The readings on this curve range from 105 per cent. of the international r.p.m. down to 70 per cent.

Throttle-power Consumption Curve

The throttle-power consumption curve indicates the normal characteristics of the carburettor, and its h.p. curve must simulate the power absorbed at sea-level by an airscrew designed for maximum power at the all-out level height. Therefore the h.p. is estimated for the airscrew law, that h.p. varies as the 2·8 index of the r.p.m. and directly as the density. Usually sufficient data are available from previous tests to determine the all-out level power of the engine, but should this not be so, then it would be necessary to complete the full throttle altitude curve before the throttled power-consumption curve.

The curve is commenced at the highest r.p.m. at which it is considered safe to run the engine without severe detonation, and the mixture control may be in the normal or full rich position, depending upon the boost developed. Readings of power, boost, and fuel consumption are recorded on the "Bristol" engines at every 200 r.p.m.

The curve is repeated with the mixture control set at each speed to

give the weakest mixture for maximum power. At each reading the mixture control is gradually weakened off until the load just commences to fall and the h.p., r.p.m., and fuel consumption recorded.

The Altitude Curve

The most important curve so far as fully supercharged engines of the Mercury VIII type are concerned is the altitude curve. In all testing described up to now a forward type of intake is used, similar to the form of intake used in actual service. For the altitude curve a special intake with the inlet tunnel towards the rear of the engine is employed as shown in Fig. 6. The air intake is connected by a rubber sleeve to a pipe about 5 in. in diameter attached to a steel drum with a conical top. The purpose of the rubber sleeve is to avoid any movement of the stand cradle causing excessive strain on the carburettor or blower volute flange.

The supply of air to the engine is controlled by a shutter at the top of the box which is operated by a screwed spindle having a small handle. A depression is maintained in the box corresponding to the atmospheric pressure at the rated altitude of the engine. This depression is measured by means of a simple mercury " U " tube at a point in the intake.

The engine throttle is kept full open, therefore the altitude box has to be robust in construction, for if it collapses there is every possibility of the engine racing away and wrecking itself. When first opening the throttle to commence the altitude curve the boost pressure is carefully watched and excessive pressures are avoided by gradually closing the shutter in the altitude box as the throttle is advanced. At the same time the " U " tube recording the depression in the box is observed, and the load on the brake is adjusted to maximum climbing r.p.m. when the throttle is finally fully open and the correct depression maintained.

Power and Boost Pressure and Air Intake

The power and boost pressure and the air intake at the box are measured. A preliminary check of the power and boost is made by applying correction factors which will be described later. If the corrected boost agrees with the declared figure of maximum boost, then it is permissible to proceed with the curve, but if the variation is, say, more than $\frac{1}{4}$ lb. boost, then a further check reading is necessary with the depression in the box corresponding to a lower or higher altitude than that recorded during the check, depending on whether a higher or lower boost is required.

The altitude curve for the type test engine is taken over a range of speeds from 105 per cent. of the maximum all-out level r.p.m. down to 70 per cent. Readings are taken at approximately every 100 r.p.m. both down and up the curve with a constant pressure in the intake, more

HORSE-POWER AND BOOST CORRECTION FACTORS

	Correction for Observed H.P.									Correction for Observed Boost							
P_o	*Alt.* 11,000′ *P*1 = 19·79		*Alt.* 12,000′ *P*1 = 19·03		*Alt.* 13,000′ *P*1 = 18·29		*Alt.* 14,000′ *P*1 = 17·58		P_o	*Alt.* 11,000′ *P*1 = 19·79		*Alt.* 12,000′ *P*1 = 19·03		*Alt.* 13,000′ *P*1 = 18·29		*Alt.* 14,000′ *P*1 = 17·58	
	A	*B*	*A*	*B*	*A*	*B*	*A*	*B*		*C*	*D*	*C*	*D*	*C*	*D*	*C*	*D*
27	336	307	325	293	315	281	304	267	27	857	850	799	790	741	730	683	670
28	327	298	315	284	305	272	294	258	28	807	800	749	740	691	680	633	620
29	319	291	306	276	296	263	285	250	29	747	740	689	680	641	630	593	580
30	310	282	297	267	287	255	276	242	30	697	690	649	640	601	590	553	540
31	302	275	289	260	278	247	266	233	31	657	650	609	600	561	550	513	500
32	293	267	281	252	270	239	259	226	32	607	600	569	560	521	510	483	470
33	286	260	272	244	261	231	250	218	33	567	560	529	520	491	480	453	440
34	278	253	263	236	253	224	241	210	34	537	530	499	490	471	460	433	420
f	1·116		1·126		1·135		1·145										

f = correction for exhaust back pressure and temperature.

$$\text{Corrected H.P.} = \text{observed H.P.} + \frac{A + t_o}{B}$$

t_o = observed intake temp.

$$\text{Corrected boost} = \frac{C + t_o}{D}$$

t_o = observed intake temp.

P_o = absolute observed blower delivery pressure.

often referred to as the depression, corresponding to the barometric pressure at the rated altitude as determined from the check run. While one tester adjusts the shutter to give the required depression, a second tester adjusts the brake load to give the required engine speed. The two operations have to be done in unison, for of course an alteration in engine speed affects the depression in the boxes.

The fuel consumption is operated by adjustment of the mixture control, if necessary, at each reading, and at each point on the curve the brake load, speed, observed boost pressure, fuel consumption, and, a very important item, the air temperature in the boxes are logged. Each set of readings on the curve is taken during the last minute of a three-minute run.

On the altitude curve it is permissible to use a higher octane fuel than that called for in service to offset any tendency of the engine to detonate and possible over-heating at the high boost pressures developed at the higher range of speeds with the engine running at full throttle.

The observed powers and boosts recorded on the curve are lower than those actually developed by the engine under actual altitude conditions, for on the ground test the air-intake temperature and exhaust back pressure are higher and the blower efficiency is lower. The result is that correction factors have to be applied to determine the performance of the engine which will be available at rated height.

Performance of Engine at Rated Height

To determine this performance a series of imperial formulæ have been supplied by the Air Ministry based on combined bench and flight test results. The corrections include :

(*a*) Correction of compression ratio of the blower for low temperature at altitude.

(*b*) The corrected boost pressure is determined by multiplying the standard atmospheric pressure at rated altitude by the corrected blower compression ratio.

(*c*) Observed power correction for the corrected boost pressure.

This is directly proportional to the absolute pressure.

(*d*) Correction for standard atmospheric temperature 15° C. and then correct for the temperature at rated altitude. These are inversely proportional to the square root of the absolute temperatures.

(*e*) Correction of exhaust back pressure.

To have to go through all these stages to determine the correct performance is a long and laborious process, and has been avoided by the use of a series of constants which have been prepared covering the various boost pressure and temperature conditions likely to be experienced during the testing of a supercharged engine. Typical examples of these charts which have been officially approved are shown in the accompanying table and are self-explanatory.

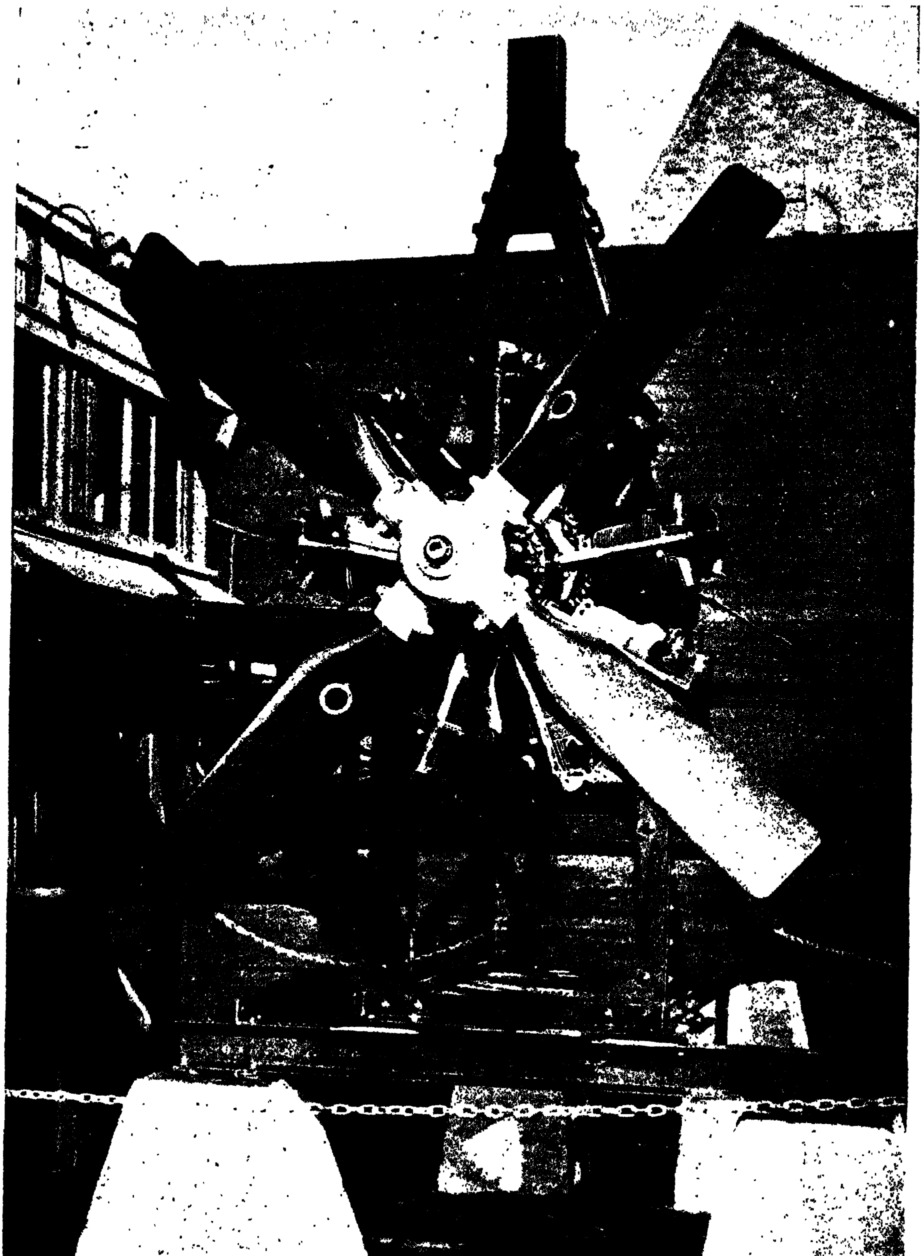


Fig. 7.—HANGAR TEST STAND FOR FIXED PITCH AIRSCREW TESTING

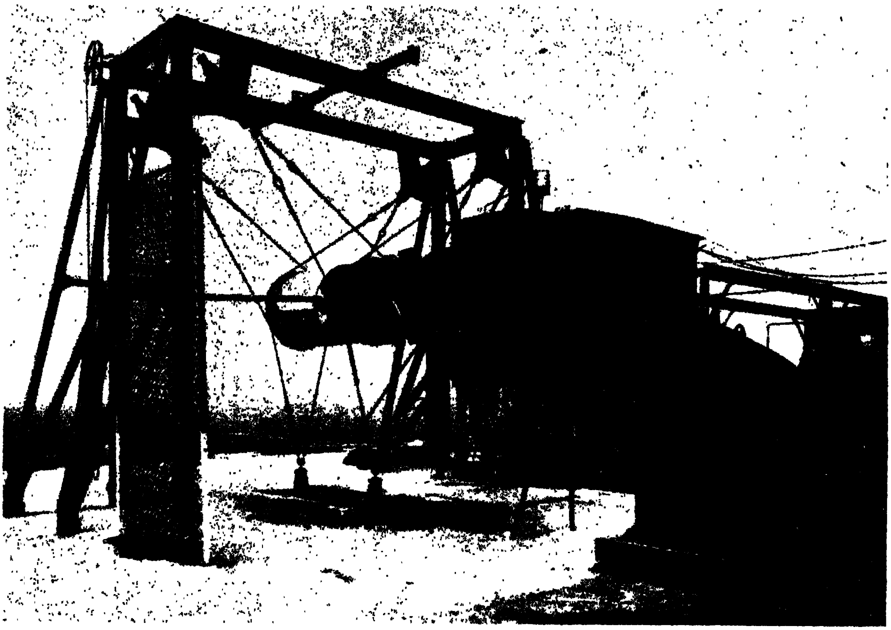


Fig. 8.—Hangar test stand for v.p. airscrew testing

Endurance Testing on Type Test

The curves having been satisfactorily completed, any modifications to the rating found necessary are forwarded to the Air Ministry in the form of amendments to the "Declaration," and the engine may proceed with its 100 hours' endurance testing if full military approval is required, or 50 hours if the engine is only intended for civil flying.

The 100 hours is completed in non-stop 10-hour periods at the following conditions :

Dynamometer. (*a*) 30 hours at maximum cruising r.p.m. and boost. (Mercury VIII 2,400 r.p.m. and + $3\frac{1}{2}$ lb./sq. in. boost.)

(*b*) 10 hours at maximum climbing r.p.m. and boost. (Mercury VIII 2,650 r.p.m. and + 5 lb./sq. in. boost.)

Hangar. (*c*) 20 hours at maximum climbing r.p.m. and boost.

(*d*) 20 hours at maximum cruising r.p.m. and boost.

(*e*) 10 minutes slow running at not more than 600 r.p.m. followed by five accelerations up to + 5 lb. boost.

(*f*) Six readings on a throttle curve at normal mixture and repeated at weakest mixture for maximum power.

Dynamometer. (*g*) 10 hours at maximum cruising r.p.m. and boost.

(*h*) 5 hours at maximum take-off r.p.m. and boost. (Mercury VIII 2,650 r.p.m. and + 5 lb./sq. in. boost.)

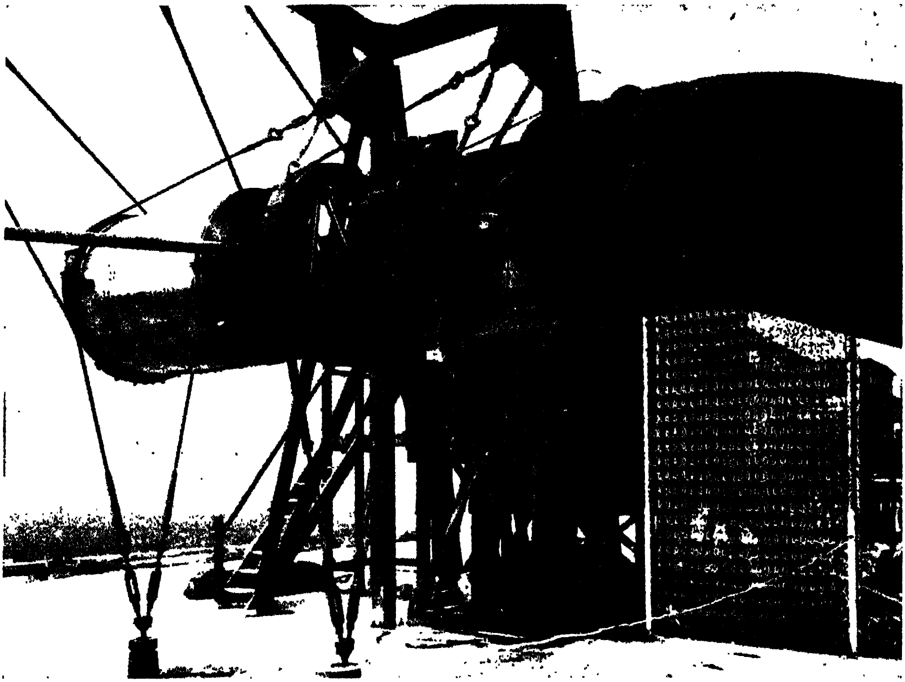


Fig. 8A.—ANOTHER VIEW OF HANGAR TEST STAND FOR V.P. AIRSCREW TESTING

(*i*) 4 hours at "fixed pitch" airscrew take-off conditions. (Mercury VIII 2,040 r.p.m. and + 5 lb./sq. in. boost.)

(*j*) 1 hour high power at maximum all-out level r.p.m. and maximum take-off boost. (Mercury VIII 2,750 r.p.m. and + 5 lb./sq. in. boost.)

(*k*) 1 hour high speed at 5 per cent. in excess of maximum all-out level r.p.m. and less than 30 per cent. rated power. (Mercury VIII 2,900 r.p.m. and 210 h.p.)

The constant boost and altitude curves specified at the commencement of the test are then repeated and this concludes the type test. The engine is returned to the shop for strip, examination, and dimensional check.

It will be noted that after the first 40 hours of the endurance carried out on the dynamometer the engine is transferred to a hangar test stand. This is the term applied to the test stand to which the engine is mounted when running with an airscrew fitted. If the engine is to be cleared for use of a fixed pitch airscrew, then a hangar stand of the type shown in Fig. 7 is employed, but most of the Bristol engines are cleared to use variable pitch metal airscrews and are tested on the stand shown in Fig. 8. The cabins of these stands are fitted with similar recording instruments to those used on the dynamometer, but no apparatus for direct measurement of the h.p. is fitted. The power can be estimated

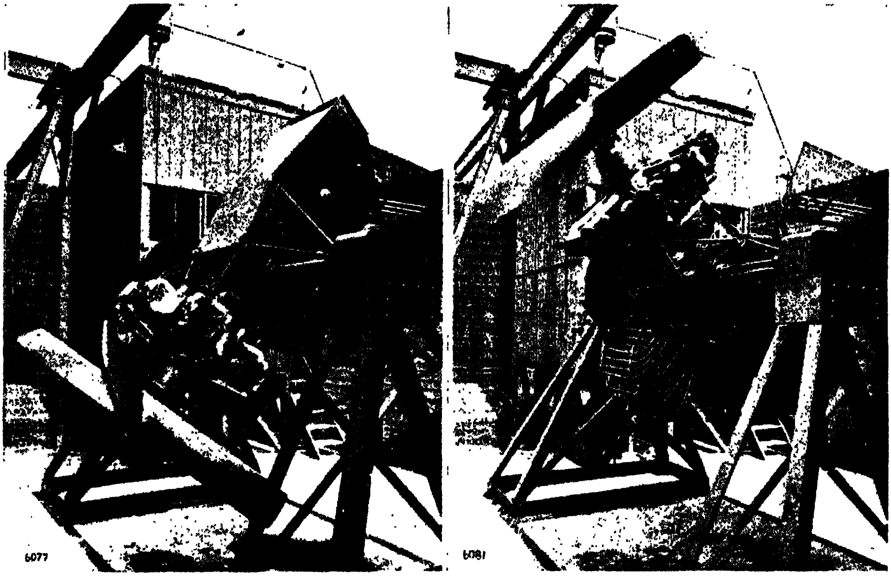


Fig. 9.—HANGAR TILTING STAND

quite accurately from the speed and boost figures once the engine has been calibrated on a dynamometer.

Starting on the hangar stands is accomplished by means of the electric starter fitted to the engine, and must be carried out three times at the commencement of each 10 hours.

Throughout the 100 hours' endurance, readings which have already been mentioned are recorded once every quarter of an hour. The cylinder temperatures on all cylinders are recorded at least once every hour.

Although the 100 hours' test represents the type test of the engine, and although the strip condition may be quite satisfactory at the conclusion of the test, full approval is not granted by the Air Ministry until further supplementary tests are completed.

One of these tests is of 50 hours in non-stop 10-hour periods at the maximum power which can be attained for continuous running at economical mixture strength. This power has to correspond as nearly as possible to 66 per cent. of the all-out level power. On such tests as this the Bristol Aeroplane Co. adopt the method of reducing the fuel consumption to a point at which the engine speed drops by 3 per cent. due to weakness of the mixture and then regain the power by opening the throttle.

The strip of the engine on the completion of this test must be of very high standard, and only when the test is completed satisfactorily can the engine be cleared to go into production.

If inclination tests for carburation and sump scavenging are required the tilting stand shown in Fig. 9 is used.

Testing of Series Engines

Up to the stage of the initial curves, series engines are submitted to the same procedure as the type engine. The curves required on final acceptance tests are fewer in number. The throttle curve is omitted and only five readings are taken on the constant boost and altitude curves.

When the altitude curve is completed the engine is run for 10 minutes on a straight fuel in order to clear the tetra-ethyl-lead which may be left in the cylinders after running on the high octane fuel, as the engine may have to wait some time before it can carry out its slow running and acceleration tests on the hangar.

The concluding test of the series acceptance test is carried out on a hangar stand. The engine is fitted with a flight airscrew to simulate as far as possible the conditions in service for slow-running and acceleration tests. Starting is carried out by means of the engine's own electric starter, and after running at 800 r.p.m. for 10 to 15 minutes the engine is opened up gradually and the cruising and maximum boosts checked and the flow-meter readings noted.

The engine is throttled back to a slow-running speed of 500 r.p.m. and any adjustment of the slow-running mixture strength is made so as to avoid " building up " (i.e. collecting of fuel in the induction system, resulting in a gradual loss in speed due to richness). The slow-running stop is set to give a speed of 500 r.p.m. and after running for 5 minutes the engine is accelerated to cruising boost. There must be no signs of " cutting-out " and yet the mixture must not be excessively rich. The accelerations are repeated from various speeds to be absolutely certain that there are no " flat " spots on the throttle-consumption curve.

Checks are made to determine that the variable pitch control is working satisfactorily and that the slow-running " cut-outs " are effective. These latter units are fitted to the carburettor fuel supply to the slow-running jets and their purpose is to prevent the engine continuing to run, due to hot plugs and valves, after the magnetos are switched off. The ignition is checked with the engine running at maximum boost, each magneto being switched off alternately and the drop in r.p.m. noted. The maximum permissible drop is 5 per cent.

When these checks are completed the engine is run for 15 minutes on a " straight " fuel, i.e. no lead content, and the sump filter is given a final examination. If this is found to be satisfactory the engine is returned to the running-in shop and motored over for a period of 10 minutes on cold mineral oil. This ensures that all internal surfaces are given a coating of oil, whereas if the engine is stored after being shut down when hot the oil film is apt to dry off.

It will be noticed that every precaution is taken on new engines, and it will no doubt be considered that the procedure is expensive and complicated. But experience has shown that the precautions have proved economic in the long run.

Chapter IV

MATERIALS TESTING

THE engineer is responsible for producing an enormous number of things used in the world to-day, and the range of materials at his disposal for this purpose increases rapidly year by year. As each new material is introduced, it is tested in as many ways as possible, so as to obtain as much information as is available about its properties. A knowledge of these properties is essential before the material can be used in the design of any product. No material is perfectly homogeneous, and it is necessary that samples of every material should be tested to ascertain its properties when dealing with engineering work of any importance.

Objects of Testing Materials

The objects of testing materials may be :

(1) Scientific ; or
(2) Commercial.

The aim of scientific testing is to find out what are the properties of the material under test, while the purpose of commercial testing is to see if the properties conform to certain specifications or lie between certain fixed limits. In commercial testing procedure, the tests are carried out for the purpose of quality control, and specifications are drawn up by such concerns as the British Standards Institution (B.S.I.), the Aeronautical Inspection Directorate (A.I.D.), and similar bodies.

TENSILE TESTS

One of the most important properties of a material is its tenacity, or its tensile strength. This property is determined by subjecting a prepared specimen to a tensile pull in a testing machine.

Testing Machines

Tensile testing machines are designed to apply a pull to a specimen, and at the same time to measure the pull applied. Thus a straining mechanism and a load-measuring device are incorporated in the machine. The straining mechanism usually consists either of a nut and screw, or a hydraulic cylinder and piston ; while the load-measuring device consists usually of either a lever carrying a movable counterpoise (on the principle of a steelyard), or of a gauge which measures the fluid pressure acting in the hydraulic cylinder.

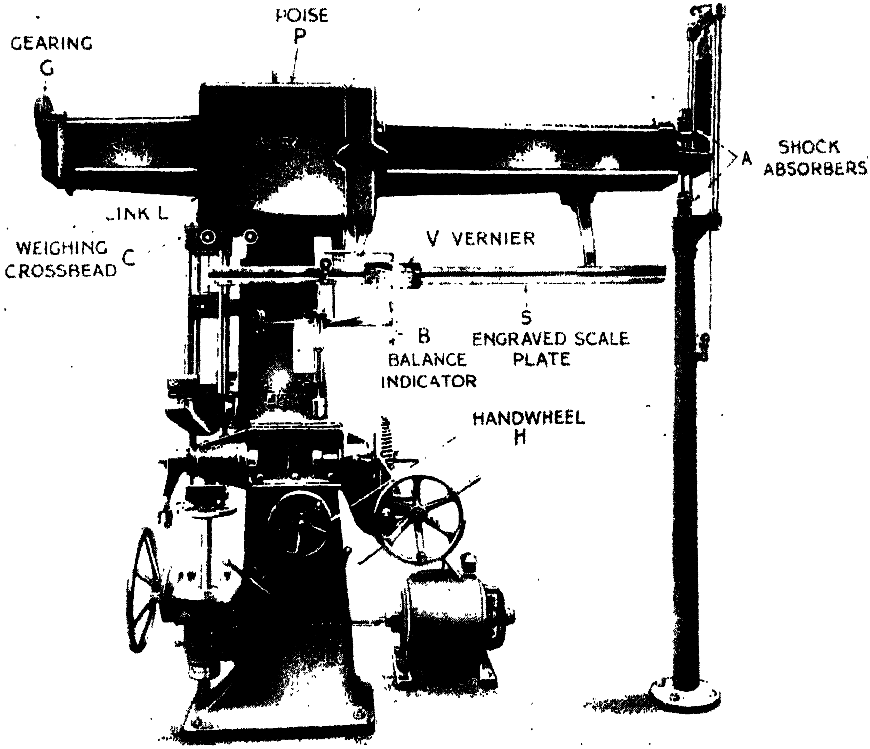


Fig. 1.—AVERY VERTICAL SINGLE-LEVER TYPE TENSILE-TESTING MACHINE

Fig. 1 shows a vertical single-lever type of machine. The poise (*P*) runs along the beam, its position being controlled by a screw and gearing (*G*). The beam is supported on a knife-edge on the top of the machine standard, and a link (*L*) carries the weighing crosshead (*C*). The position of the poise is indicated on the Vernier (*V*) which moves along the scale (*S*); the balance indicator (*B*) indicates when the beam is balanced. Shock absorbers (*A*) are fitted to the right-hand end of the beam as shown.

In some cases multi-lever machines are used instead of the single-lever type.

Methods of Holding Specimen

When ductile materials are tested in tension, the ends of the specimen are usually held in wedge grips, which hold the specimen firmly as the pull is applied. Fig. 2 shows a specimen held in such a manner. For brittle materials special shackles have to be used to ensure that the load is perfectly axial, so that bending stresses are not set up in the specimen.

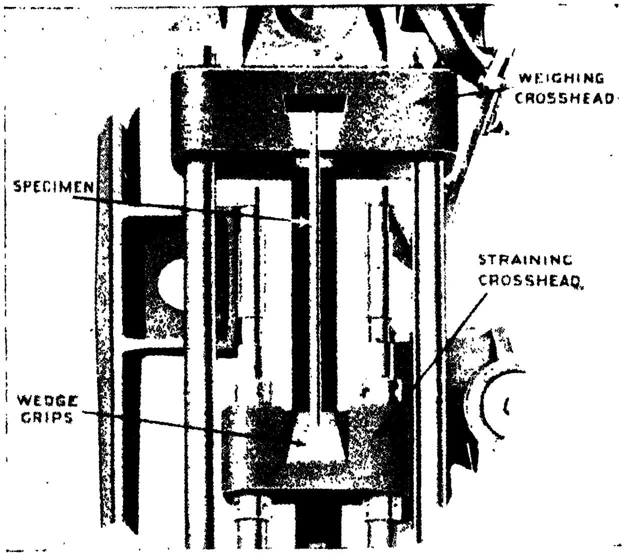


Fig. 2.—Wedge grips holding tensile specimen (*Avery*)

Extensometers

When the pull is applied to a specimen, it extends or stretches. Under normal loads this extension is very small, and sensitive extensometers are used to measure it. The instruments are made to fit on definite gauge lengths. The principle on which these extensometers work varies, and several well-known types will be mentioned.

Fig. 8 shows a Cambridge extensometer. This instrument is made in two separate pieces (*A* and *B*), each of which is separately attached to the test-piece (*TP*) by means of knurled headed hardened steel conical-pointed screws (*SS*). Both parts of the instrument are capable of rotating freely about these points. The lower piece carries a micrometer screw (*S*) fitted with a hardened steel point (*P*) and a divided head. It also carries a vertical arm, on the top of which is a hardened steel knife-edge (*K*). The upper and lower pieces work together about this knife-edge. A flexible steel tongue (*T*) forming a continuation of the upper piece is carried over the micrometer point (*P*). This tongue acts as a lever magnifying the extension of the specimen, so that the movement of the steel tongue (*T*) to or away from the steel point (*P*) is

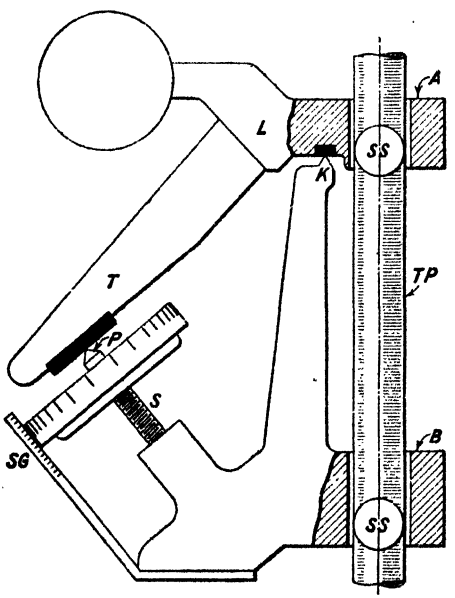


Fig. 3.—Diagram illustrating the Cambridge extensometer

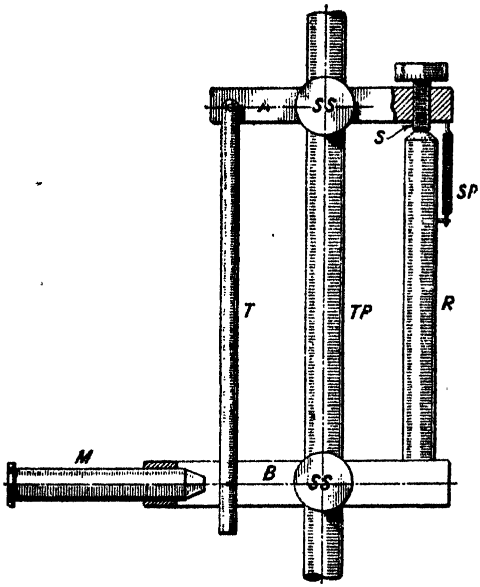


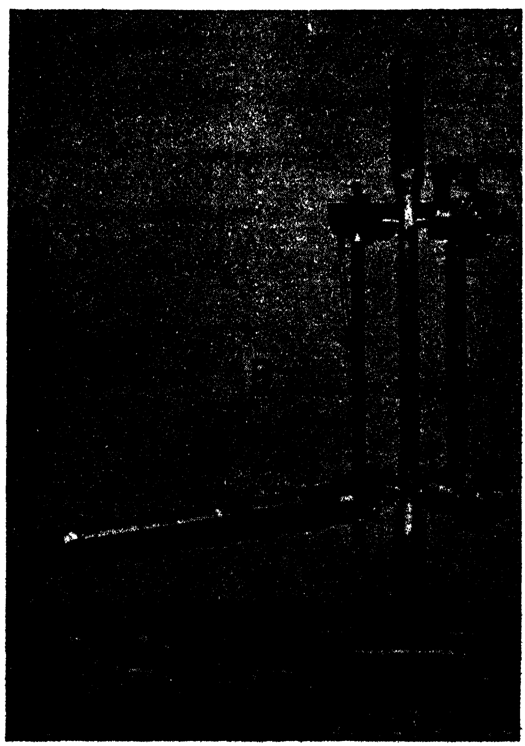
Fig. 4 (*above*).—DIAGRAM ILLUSTRATING THE PRINCIPLE OF THE EWING EXTENSOMETER

five times the actual extension of the specimen. To take a reading with the extensometer, the thin steel tongue (*T*) is caused to vibrate and the divided head then turned until the point (*P*) just touches the hard steel knife-edge on the tongue as it vibrates. This is a delicate method of setting the micrometer screw, as the noise produced and the fact that the vibrations are quickly damped out indicate to $\frac{1}{1000}$ mm. the instant when the screw is touching the tongue. After the load is applied a second reading is taken in a similar manner, and the difference in the readings gives directly the extensions of the test-piece.

The "Ewing" Extensometer

The "Ewing" extensometer is shown in Fig. 4. In this instrument a microscope (*M*) is fixed to the bottom part, and a rod in which is fixed a cross-wire is connected to the top part. Any relative movement of the two parts, which occurs when the specimen extends, is indicated by the cross-wire moving across a graduated scale viewed through the microscope.

Fig. 5 (*below*).—THE EWING EXTENSOMETER



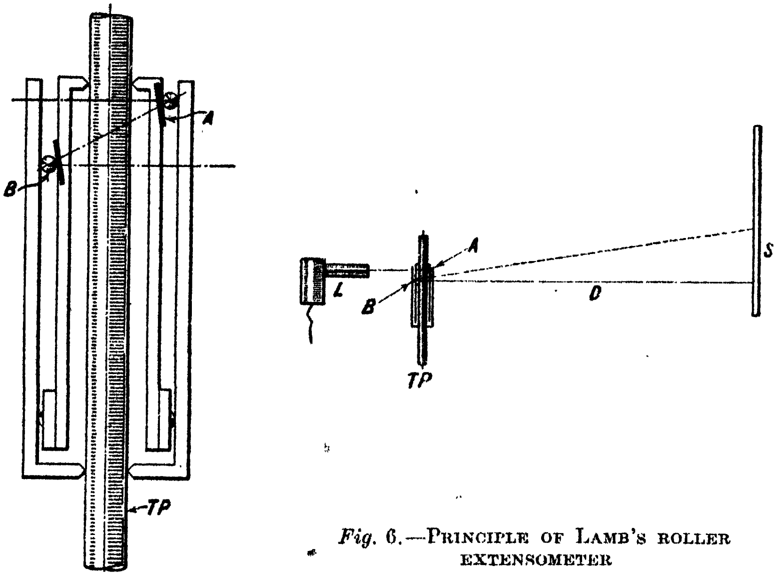


Fig. 6.—Principle of Lamb's roller extensometer

Lamb's Roller Extensometer

Lamb's roller extensometer is shown in Fig. 6. Two small mirrors (A and B) are each fixed to a roller. These rollers are held between steel strips, one of which forms the upper element and the other the lower element. Any extension of the specimen causes these strips to move and the rollers to rotate, carrying the mirrors with them. A lamp or a telescope is directed to the first mirror (A). The mirror reflects the image of the scale (S) as shown in Fig. 6. If a lamp is used, the image of cross-wires in the lamp are seen on the scale (S). The distance from the scale to the instrument can be arranged to give a large magnification, and thus enable small extensions to be measured.

The extension e is given by :

$$e = \frac{dx}{4\left(D+\frac{a}{2}\right)}$$

Where $d =$ mean diameter of the rollers, in inches.
$x =$ scale reading.
$D =$ distance from mirror to scale.
$a =$ distance between the two mirrors.

Direct Reading Extensometers

Direct reading extensometers using a dial gauge are very popular for test-house work. Fig. 7 shows an extensometer of this type.

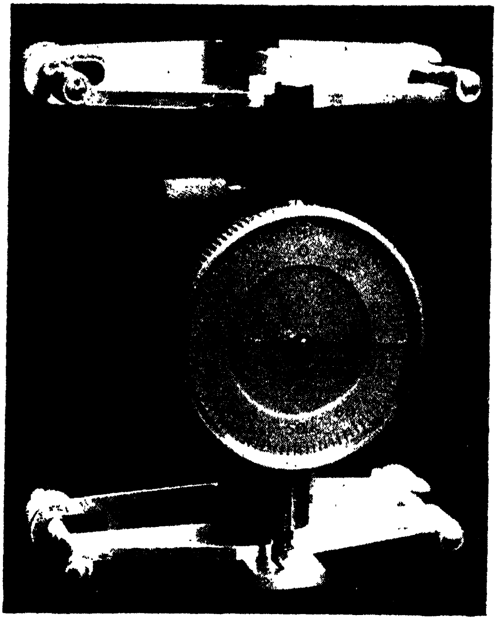


Fig. 7.—DIAL-GAUGE EXTENSOMETER

Marking Off Gauge Length

Marking-off tools are sometimes used, to ensure that the extensometer is fitted to the correct gauge length. A marking-off tool is shown in Fig. 7A. The specimen is held in a vee-block with a screwed clamp, the cylindrical centre punch being laid in each of the four vees shown, and given a light tap. Four centre pops are thus made, in which are clamped the extensometer points.

Test Calculations

The tensile stress in the specimen is the number of pounds (or tons) to the square inch of cross-sectional area; or

$$Stress = \frac{Load}{Area}.$$

The specimen will extend as mentioned and the strain is given by

$$Strain = \frac{Extension}{Original\ length}.$$

Many materials possess, to a certain degree, the property of elasticity, that is, they will return to their original dimensions when any stress is removed. When a graph is plotted between stress and strain for such materials, it is found to be a straight line up to a certain stress. Fig. 8 illustrates such a graph. The slope of the straignt line portion of the graph

$$= \frac{AX}{BX}$$

gives the value $\frac{Stress}{Strain}$,

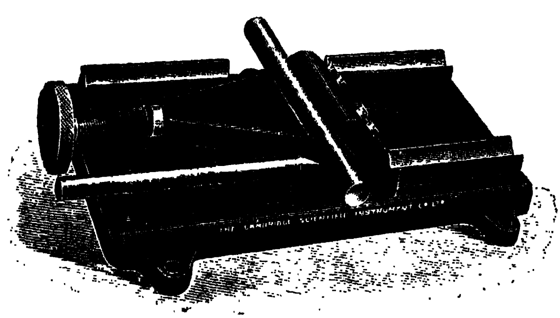
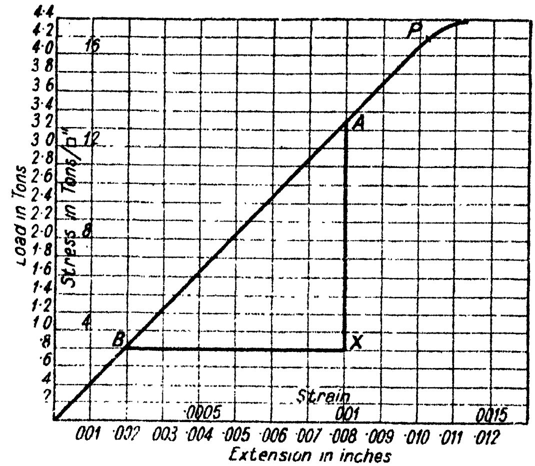


Fig. 7A.—MARKING-OFF TOOL
(*Cambridge Instrument Co., Ltd.*)

Fig. 8 (*right*).—TENSILE TEST STRESS-STRAIN DIAGRAM

If a graph is plotted between stress and strain, the points lie on a straight line, and this "straight line law" is known as Hooke's law. The point (P) where the line begins to curve over slightly is called the "Limit of Proportionality." Up to this point the material is more or less elastic, but beyond that limit the specimen acquires permanent set.



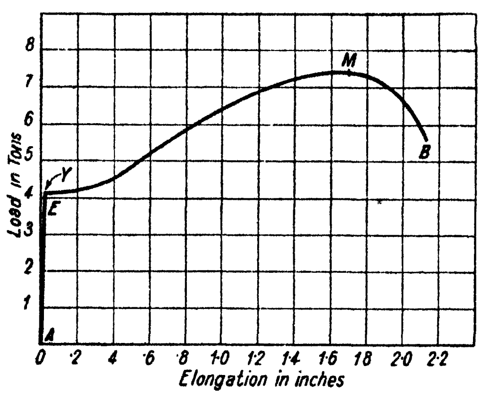
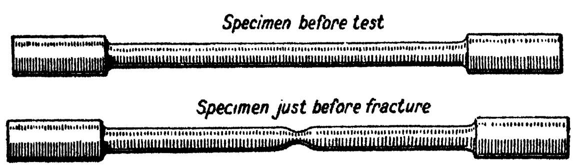
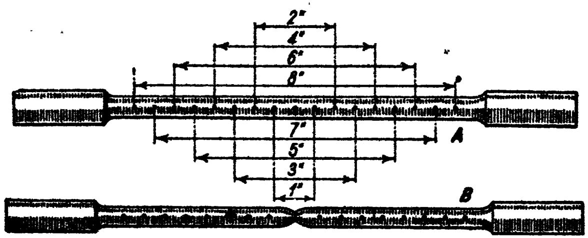


Fig. 8A (*left*).—TYPICAL DIAGRAM OF TENSILE TEST ON MILD STEEL

Showing a load-extension curve. The portion A E is the straight line where stress and strain (and therefore load and extension) are proportional. E is the limit of proportionality (only found by very careful tests with accurate strain-measuring instruments). Shortly after E is the yield point (Y), where a large extension of the specimen takes place without any increase in load. The material yields for a time and then it becomes necessary to increase the load again, but much more slowly than previously. At the maximum load point (M), a neck begins to form on the specimen (as shown in Fig. 8B), when it becomes necessary to reduce the load, as shown. B is the point where the break occurs.

Fig. 8B (*right*).—APPEARANCE OF MILD STEEL SPECIMEN BEFORE AND DURING TENSILE TEST





Original Gauge Length	1"	2"	3"	4"	5"	6"	7"	8"
Extended Gauge Length	1·54	2·83	4·06	5·3	6·57	7·74	8·96	10·12
Elongation %	54	41·5	36	32·5	31·4	29	28	26·5

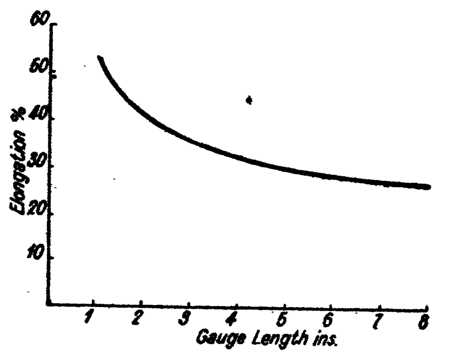
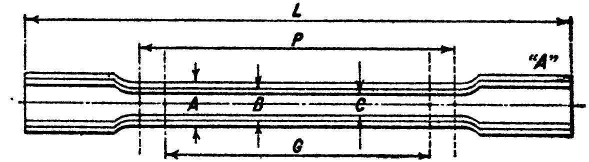


Fig. 8C.—RESULTS OF TENSILE TEST ON MILD STEEL BAR ·564 IN. DIAMETER BY 8-IN. GAUGE LENGTH

A, piece before test, the gauge length being marked every ½ in. with dots; *B*, the same piece after fracture. Table shows the original gauge length, the extended gauge length and the elongation per cent. Graph shows influence of gauge length on elongation per cent.



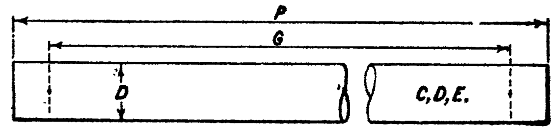


Plate Test Piece "A" G = 8", P = 9", L = about 18"
Plate thickness under ⅜", A = 2½"
" " ⅜" to ⅞", B = 2"
" " over ⅞", C = 1½"

Round Test Pieces

Test Piece	D	G	P
C	·564"	2"	not less than 2¼"
D	·798"	3"	" " " 3¼"
E	·977"	3½"	" " " 4"

Note:- ·564" diam = ¼ □" area
·798" " = ½ □" "
·977" " = ¾ □" "

Fig. 8D.—BRITISH STANDARD DIMENSIONS FOR TEST-PIECES

Fig. 8C shows that in order to estimate the ductility of a material from a test, the gauge length and cross sectional area must be stated. The B.S.I. recommendations relating to dimensions of plate and round test pieces are illustrated above. *P* is the parallel length of the test-piece; *G*, the gauge length.

and this is constant for that particular material.

This ratio $\frac{Stress}{Strain}$ is called the Modulus of Elasticity, and is denoted by E. The point (P) at the end of the straight-line portion is called the "Limit of Proportionality," and at this point the strain increases at a greater rate then before. If the stress is taken beyond this point the material will not return to its original length, but will have stretched permanently.

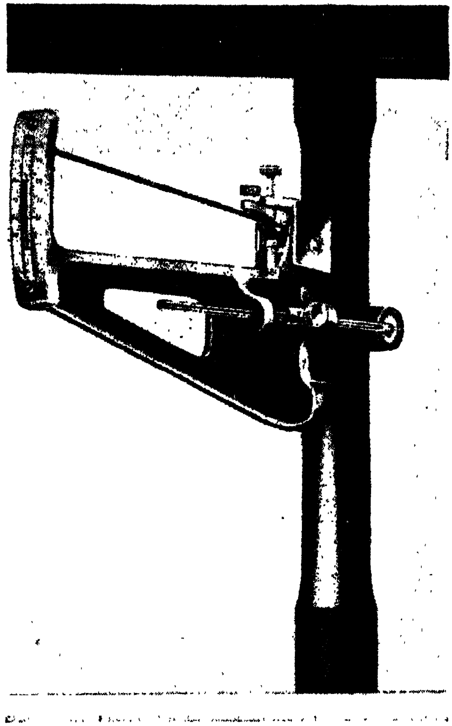


Fig. 9.—YIELD-POINT INDICATOR. (*Avery.*)

Yield Stress

Some materials exhibit a definite yield point after the limit of proportionality is past, and this may be needed in specifications. A yield-point indicator is shown in Fig. 9. This instrument shows the sudden extension of the specimen which occurs at the yield point. Ductile materials extend, becoming thinner over their whole length, until the maximum load is reached. At this point, one part of the gauge length begins to form a "neck," and the load must be reduced to prevent fracture taking place. The extension now takes place in the region of this neck, and is called a "local" extension. The nominal stresses at the yield point, maximum load, and breaking load are given by dividing the load at each point by the original cross-sectional area. The true stress at the breaking load will be higher than the nominal stress, since the cross-sectional area is considerably reduced.

Ultimate Strength

The ultimate strength of the material is the nominal stress at the maximum load; that is, the maximum load carried by the specimen divided by the original cross-sectional area. After the specimen has been fractured, the two parts are put together and the diameter at the fracture is measured; from this reduced diameter the area at the fracture is calculated and the reduction of area per cent. is calculated from :

$$\text{Reduction of area per cent.} = \frac{A - a}{A} \times 100,$$

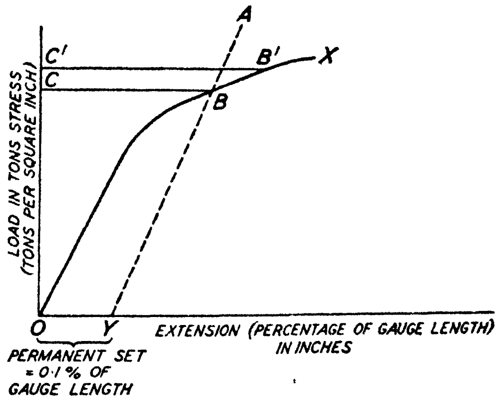


Fig. 10.—LOAD EXTENSION GRAPH FOR PROOF STRESS DETERMINATION

where A is the original cross-sectional area, and a is the cross-sectional area at the fracture.

The extended gauge length is also measured and the elongation per cent. is calculated as follows:

$$\text{Elongation per cent.} = \frac{L - l}{l} \times 100,$$

where L is the extended gauge length, and l is the original gauge length.

These expressions give some indication of the ductility of the material.

Proof Stress

On some materials, such as alloy steels and bronze, the yield point is non-existent, and it is impossible therefore to calculate yield stress. The development of alloys for aircraft construction has led to the practice of specifying, in place of yield stress, *proof stress*.

A specification might state that "the proof stress shall be defined as that stress at which the stress-strain curves depart by 0·1 per cent. of the gauge length from the straight line of proportionality."

The accompanying graph (Fig. 10) shows the stress strain curve ($O\,X$) of a steel specimen, and it is required to know whether this specimen passes the specification as regards proof stress. 0·1 per cent. of the gauge length is marked off on the extension and equals $O\,Y$. A line ($Y\,A$) is drawn parallel to the elastic part of the curve $O\,X$, intersecting $O\,X$ at B corresponding to stress $O\,C$, which is the proof stress. If the proof stress had been specified as $C^1\,B^1$, the specimen would not pass the specification.

In practice, the proof stress is specified and is applied to the specimen for a definite time, say fifteen seconds, and when this stress is removed, the permanent set resulting from this stress must not exceed 0·1 per cent. of the gauge length.

Normally, the tensile-testing machine is loading the specimen in continuously increasing measure until fracture. To obtain the application of the specified load for the stipulated time, provision must be made for load maintenance. This is a simple matter on a tensile-testing machine, which has a lever-weighing system, as the poise on the beam is set at the required load before the machine is started up. On machines with a hydraulic weighing system, special provision is made for

maintaining the load in determining the proof stress of a tensile-test specimen.

In order to comply with the proof-stress specification, accurate measurement of the extension is essential, since if a 2-in. gauge length specimen is used, this involves working to 0·002 in. An extensometer must be used and readings taken regularly, or, alternatively, an autographic-recording attachment must be fitted on the machine. The normal autographic recorder magnifies the stress-strain curve from three to ten times, although autographic recorders with much greater magnification are available commercially.

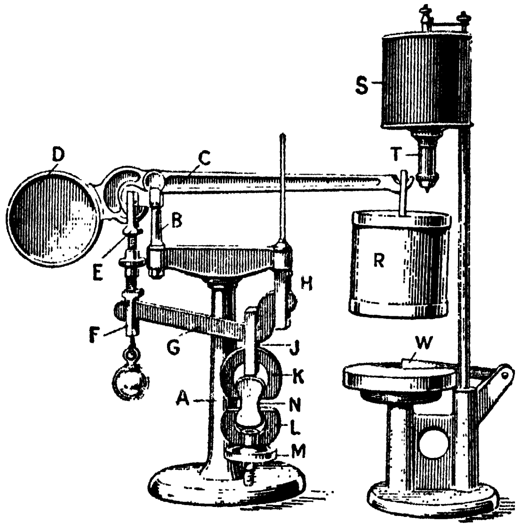


Fig. 11.—CEMENT TESTER
(*Sir W. H. Bailey & Co., Ltd.*)

When the specimen fractures, the maximum load is noted and the maximum stress calculated in a similar manner to that used in ascertaining the yield stress, mentioned previously.

Standard Test Specimens

Since the total extension of the specimen at fracture consists of general extension (which occurs until the maximum load is reached) and the local extension (which occurs after the maximum load is passed), then it will be seen that the elongation per cent. depends upon the gauge length adopted. A long specimen gives a small elongation, while a short specimen of the same material and cross-sectional dimensions will give a large elongation per cent. It is therefore necessary to specify the gauge length of the specimen when the elongation is mentioned. It has been found that geometrically similar test-pieces deform similarly, which means that so long as the ratio

$$\frac{\textit{Gauge length}}{\textit{Lateral cross-sectional dimensions}}$$

remains constant, we can expect to get comparable results for elongation. For this reason dimensions of test specimens have been standardised in various countries. The values adopted by the B.S.I. for cylindrical specimens are as follows:

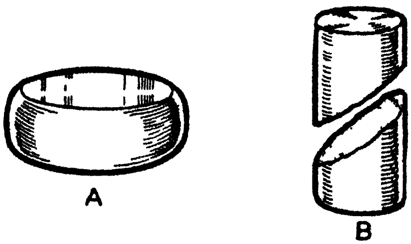


Fig 12 —COMPRESSION SPECIMENS AFTER TESTING

A, ductile material B, brittle material

Diameter (d)	Area (a)	Gauge length (l)
In	Sq In	In
0 564	0 25	2
0 798	0 5	3
0 977	0 75	3 5

The values in the above table correspond approximately to the law

$$L = 4\sqrt{a}$$

On the Continent and in America similar laws, but with a different constant, are used

Autographic Recorders

These are attachments which may be fitted to machines to record automatically the stress strain curve or the load-extension curve.

Cement Testing

Small cement briquettes are tested for tensile strength in a machine as shown in Fig 11 The briquette (N) is held between lower and upper jaws (L and K), the lower jaw being adjusted in height by the hand-wheel (M), which is fixed to a screwed spindle, the upper jaw (K) being supported from the link (J), which is carried by the subsidiary lever (G) One end of G is supported on the bracket (H), the other end being carried by the link (F), this again being supported through the link (E) by a knife-edge on the main lever (C). The bucket (R) is suspended from the main lever and is balanced by the balance-weight (D) Shot is allowed to fall from the cylinder (S) through the tube (T) into the bucket (R) This imposes a tensile stress on the briquette, and when the specimen breaks the bucket (R) drops on to the trigger (W) and stops the supply of shot. The contents of the bucket are then weighed on a

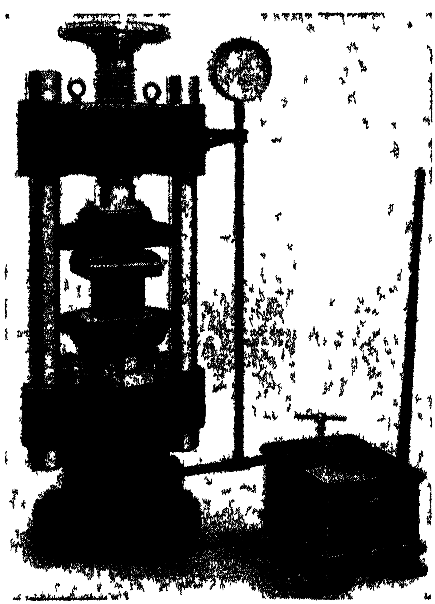


Fig 13 —AVERY COMPRESSION TESTING MACHINE

Testing a concrete cube.

scale, the dial of which is specially calibrated to read the breaking load directly.

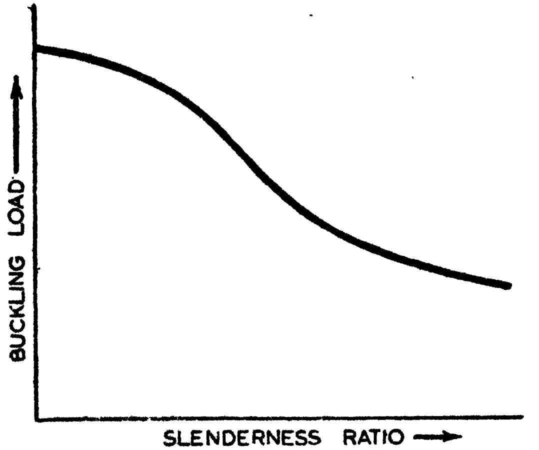


Fig. 14.—LONG STRUT CURVE

COMPRESSION TESTS

Compression tests are carried out to determine the resistance of materials to crushing. The specimen is usually in the form of a short cylinder or prism, and it is loaded between the flat platens of the machine. A cylindrical specimen of ductile material, such as wrought iron or mild steel, will flatten out as shown in Fig. 12, A. In such a case the load can be increased indefinitely, since the cross-sectional area increases with increased load. Brittle materials, like cast iron, fracture by shearing across, as shown in Fig. 12, B, when a definite maximum load is reached.

On Concrete

Compression tests are carried out on concrete cubes and cylinders. Collapsible moulds are used. These are filled with concrete, which is left to set. When setting has taken place, the moulds are removed and the specimen is tested in a machine such as is shown in Fig. 13. The large vertical screw is used to adjust the position of the top platen, and the crushing force is applied by operating the pump lever shown at

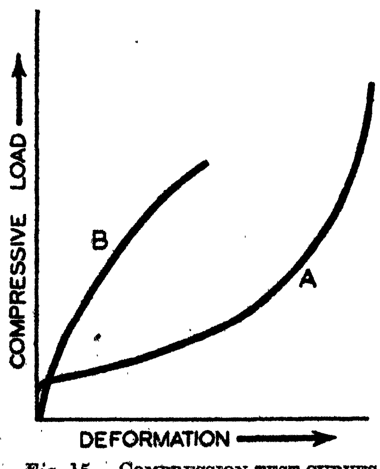


Fig. 15.—COMPRESSION TEST CURVES
A, ductile material. B, brittle material.

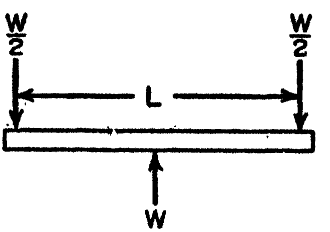


Fig. 16.—LOADING FOR TRANSVERSE TEST

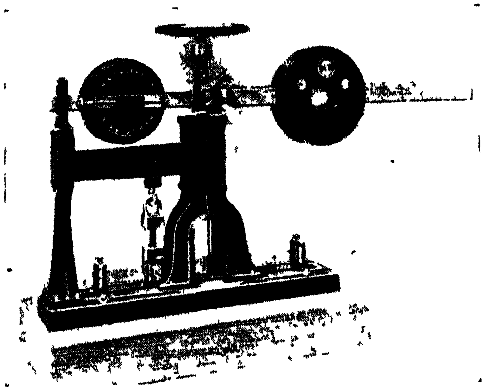


Fig 17. TRANSVERSE TESTING MACHINE.
The position of the specimen is indicated by the dotted outline (*Avery*)

the right. This forces oil into the cylinder at the base of the machine and causes the plunger to rise, carrying the bottom platen with it. The load is read on the pressure gauge shown.

Buckling Load

If a compression specimen is long compared with its cross-sectional dimensions, it will fail by buckling instead of by crushing.

Such struts are tested to find the buckling load, which varies in a manner as shown in Fig. 14.

The slenderness ratio is the ratio of the strut length to its cross-sectional dimensions. Considering a series of struts of constant cross-sectional dimensions, the slenderness ratio increases with the length, and, as will be seen from the curve, the buckling load decreases with increased slenderness ratio.

Fig. 15 shows curves of compression tests on short specimens.

TRANSVERSE TESTS

The transverse test is a standard one applied to cast-iron bars and sometimes to timber beams. Fig. 16 shows the method of applying the load in the case of cast iron. The nominal stress in the material due to bending at fracture is called the Modulus of Rupture and this is given by the expressions

$$M\,R = \frac{3WL}{2BD^2}$$ for rectangular specimens of breadth B and depth D,

and $$M\,R = \frac{8WL}{\pi d^3}$$ for circular specimens of diameter d.

A machine for carrying out transverse tests is shown in Fig. 17.

BEND TESTS

Bend tests are carried out on plate material and on welding to determine the ductility. A short length of plate is bent over a former of specified radius until a certain angle is reached or until a crack appears.

CUPPING TESTS

The tensile-strength test does not give reliable results with thin sheets, and the cupping test is applied to determine the drawing, stamping, and

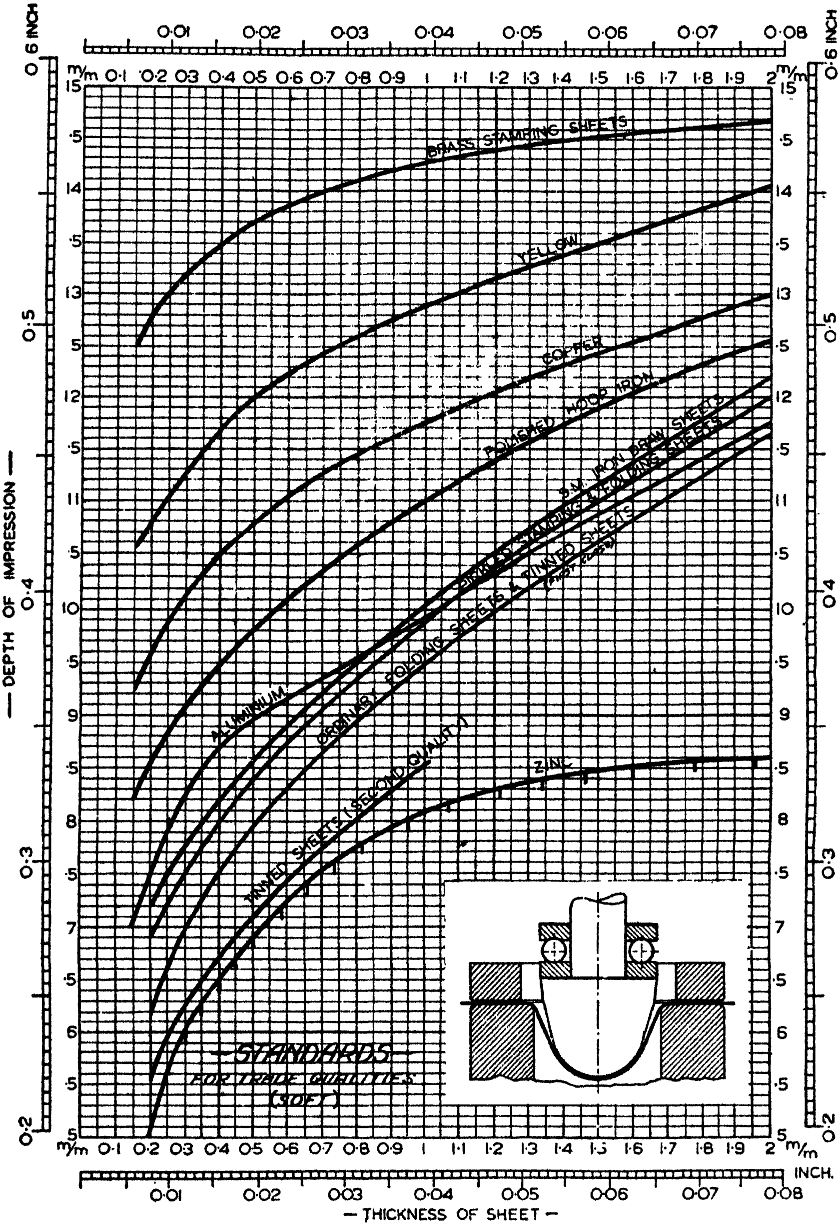


Fig. 18.—" ERICHSEN " CURVES FOR STANDARD TRADE QUALITY SHEETS
(*George H. Alexander Machinery, Ltd.*)

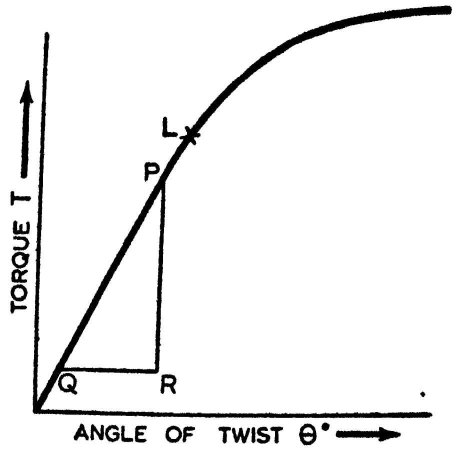


Fig. 19.—TORQUE-TWIST GRAPH

folding qualities of the specimen. A specimen of the sheet is clamped between two dies, while a tool having a rounded end (sometimes a ball) is moved forward against the sheet, forming a cup, until fracture occurs. The cup is observed during the test, so that the depth of the impression required to fracture can be read off directly from a micrometer scale on the machine. The appearance of the dome produced gives an indication as to the value of the metal for drawing purposes. If the dome is rough or fibrous, it is not suitable for deep drawing.

A section of the doming tool and sheet is shown at the bottom right-hand corner of Fig. 18. The curves of Fig. 18 show the depths of impression plotted against thickness of sheet for standard trade qualities of different materials.

TORSION TESTS

When a specimen is subjected to a torsion test or torque, shear stresses are set up in the material. The torque is given by the equation

$$T = \frac{\pi fs\, d^3}{16},$$

where fs is the shear stress at the surface, and d is the shaft diameter.

The specimen is twisted in the torsion machine which measures the torque impressed. A torsion meter is fitted which measures the angle of twist over a given gauge length.

The Modulus of Rigidity (C) is the $\frac{\textit{Shear stress}}{\textit{Shear strain}}$ and is obtained from the expression

$$C = \frac{584\, TL}{\theta\, d^4},$$

where L is the gauge length in inches ; θ is the angle of twist in degrees.

If a graph is plotted between torque (T) and angle of twist (θ), a curve of the form shown in Fig. 19 results. The first part of this curve is straight, and the slope of this straight portion $= \frac{PR}{QR} = \frac{T}{\theta}$ and this slope multiplied by $\frac{584L}{d^4}$ gives the value of C.

The shear stress at the limit of proportionality (L) is also given by

$$f_L = \frac{16\, T_L}{\pi\, d^3}$$

Where T_L is the torque at that point.

TABLE I.—LOADS AND BALL DIAMETERS
FOR BRINELL HARDNESS TESTS

Ball Diameter	*Load*			
	$\frac{P}{D^2} = 1$	$\frac{P}{D^2} = 5$	$\frac{P}{D^2} = 10$	$\frac{P}{D^2} = 30$
mm.	*Kg.*	*Kg.*	*Kg.*	*Kg.*
1	1	5	10	30
2	4	20	40	120
5	25	125	250	750
10	100	500	1,000	3,000

HARDNESS TESTS

Most methods of hardness testing consist of finding the resistance of the materials to indentation.

The Brinell Test

A hardened steel ball is pressed into the surface of the material being tested under a standard load. When the indentation has been made, the ball is removed and the diameter of the impression is measured by means of a graduated microscope. The Brinell hardness number is given by

$$\frac{\textit{Load in kilograms}}{\textit{Area of impression in square millimetres}} = \frac{P}{A}.$$

The area of the impression may be calculated from the formula

$$A = \frac{\pi D}{2}\left(D - \sqrt{D^2 - d^2}\right),$$

where D is the ball diameter.
d is the diameter of the impression.

Whenever possible a ball of 10 mm. diameter is used, but balls of 5-, 2- and 1-mm. diameter may be used. For geometrically similar impressions using different diameter balls the value $\frac{P}{D^2}$ should be kept constant. It is 30 for steel, 10 for softer alloys, 5 for copper, and 1 for lead and tin, etc. The load necessary for steel with 10-mm. diameter ball is therefore given by $\frac{P}{10^2} = 30$, therefore $P = 3{,}000$ kg. Table I

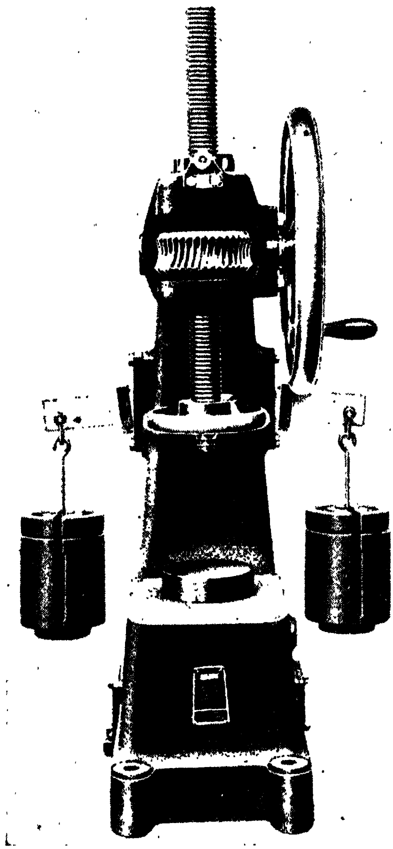


Fig. 20.—Brinell hardness-testing machine. (*Avery.*)

shows the load required according to the constant $\frac{P}{D^2}$ and the ball diameter.

The Brinell test is easily carried out, and it is often used to give an indication of the tensile strength of the material. No general rule can be applied for all materials, but for steels the approximate tensile strength in tons per square inch is obtained by multiplying the Brinell hardness number by 0·22.

A Brinell testing machine is shown in Fig. 20. The hand-wheel operates a worm, which drives the worm-wheel shown. The worm-wheel has an internal thread which mates with the spindle thread. The spindle is first adjusted so that the steel ball, held in the chuck at the bottom, is just clear of the specimen, which is placed on the machine table. The hand-wheel is turned, and this forces the ball into the metal specimen. When the required load is reached, the table, which is part of a weighing machine, causes the weights at the side to float. When the load has remained on half a minute the spindle is screwed back and the specimen examined through the microscope.

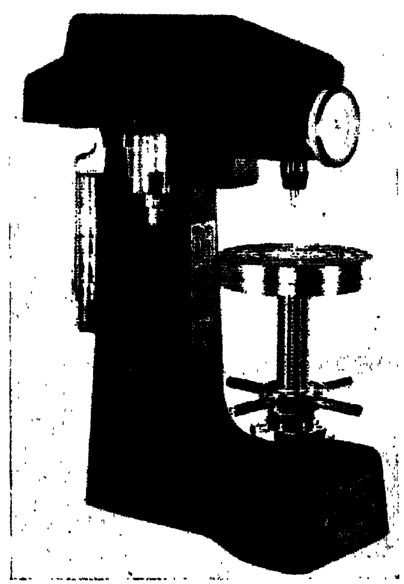


Fig. 21.—Rockwell hardness tester (*George H. Alexander Machinery, Ltd.*)

Pyramid Hardness Numerals

When a steel ball is used on hard specimens, the ball becomes

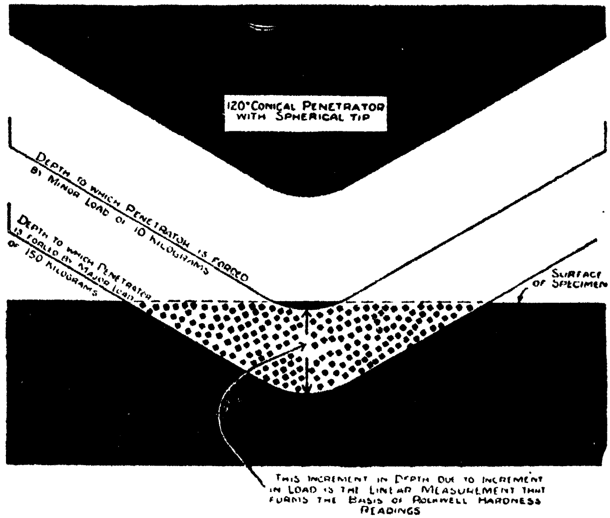


Fig. 22.—SECTION OF ROCKWELL IMPRESSION USING 120° CONICAL PENETRATOR

deformed. A diamond in the shape of a square pyramid is used with advantage in such circumstances. Another advantage of the pyramid diamond is that all the impressions are geometrically similar, whatever the hardness of the material or the load used. A diamond indenter may be used with the Brinell machine illustrated in Fig. 20. The standard angle between opposite faces of the pyramid diamond is 136°, and with this angle the pyramid hardness numeral is given by

$$N = \frac{1 \cdot 854\, P}{D^2},$$

where P is the load in kilograms.
D is the length of the diagonal impression in millimetres.

The " Firth Hardometer " is a useful machine for this purpose. In this machine, the load mechanism is operated by a hand-wheel at the top, a trip mechanism arresting the motion of the hand-wheel as soon as the correct load has been applied. After the impression is made the indentor spindle is swung away, and a microscope at the side swung into position to measure the impression.

Rockwell Hardness Test

The principle used by the Rockwell machine is based on the additional depth to which a test ball or cone is driven by a heavy load beyond the depth to which the same penetrator has been driven by a light load. The machine is illustrated in Fig. 21, and the method of carrying out the test is as follows :

(1) The specimen to be tested is placed upon the anvil or testing table.
(2) The wheel is turned to lift the work into contact with the test

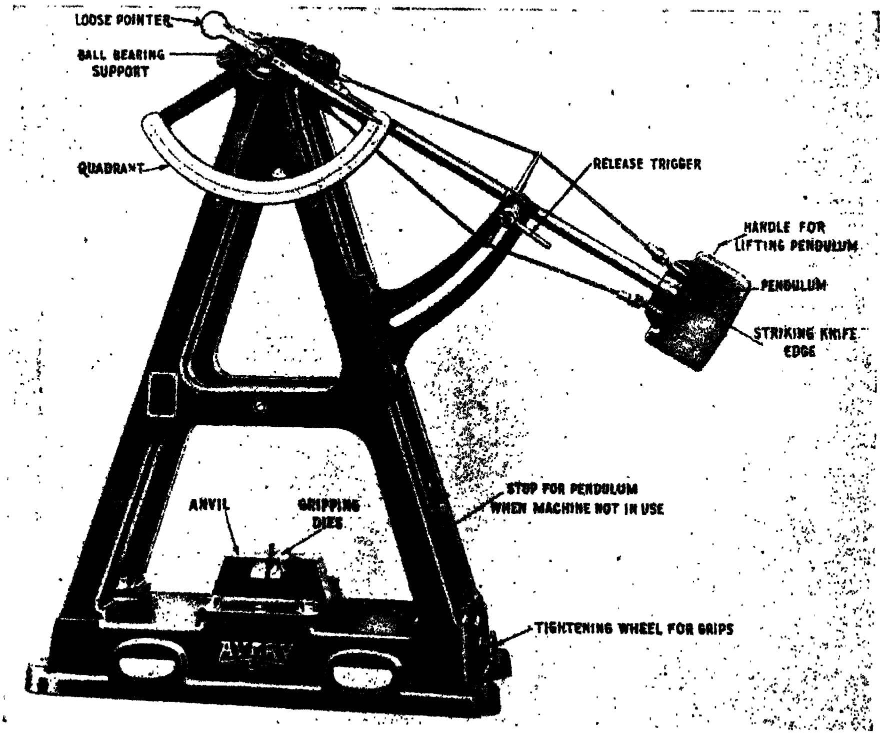


Fig. 23.—IZOD IMPACT-TESTING MACHINE. (*Avery.*)

point and force the work against the penetrator until the dial indicates that the minor load is applied.

(3) The bezel of the gauge is set to dial zero behind the pointer.

(4) The major load is applied by releasing the handle at the side of the machine.

(5) The position of the pointer is observed when it comes to rest.

(6) The handle is pulled forward, thereby removing the major load, but not the minor load.

(7) The Rockwell hardness number is then read on the dial.

Two scales may be used : a B scale and a C scale. The B scale is used when a steel ball $\frac{1}{16}$-in. diametet is used as the penetrator with 100 km. major load. The other scale is used when the diamond penetrator consisting of 120° cone with a spherical tip ground to a radius of 0·2 mm. is used, the major load in this case being 150 kg. Fig. 22 shows a section through a Rockwell impression using a conical penetrator.

Other methods of hardness testing are employed which utilise different principles.

The Scleroscope

The scleroscope consists of a tube containing a small steel hammer tipped with a diamond. The hammer can be released from the top of the instrument, so as to fall down the tube from a given height on to the specimen clamped below. The hammer rebounds up the tube, and the height of the rebound indicates the scleroscope hardness reading.

The Herbert Pendulum

The Herbert pendulum consists of a casting weighing 4 kg., having a ball or cylindrical jewel held in a chuck, so that the centre of gravity of the casting is slightly below the centre of the ball. If the ball and casting are then supported on a hard flat surface and displaced slightly from the central position, it will oscillate like a pendulum. If placed on a metal surface, the frequency of the oscillation gives an indication of the hardness of the metal. On a plate-glass surface the period of oscillation is ten seconds, the period on steel being about two to three seconds.

IMPACT TESTS

Although unknown at the beginning of the present century, the impact test has gained considerable importance.

This test reveals useful information, not only about the ability of a metal to withstand shock, but also, what is commonly more important, it proves an effective check on heat treatment. Two specimens, one correctly, the other incorrectly, heat treated, will probably not show much difference when tested in tension, but will give very different results when subjected to the impact test. The correctly heat-treated specimen will have a much higher impact value.

There are various types of machines available both for single-impact and repeated impact tests. Of the single-

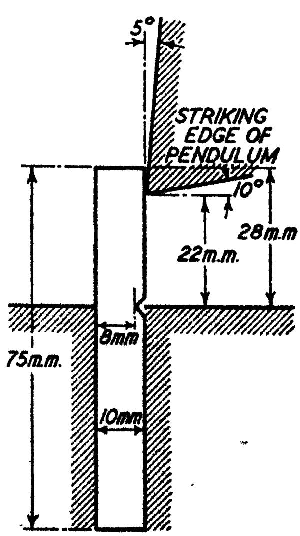


Fig. 24.—Izod standard test-piece

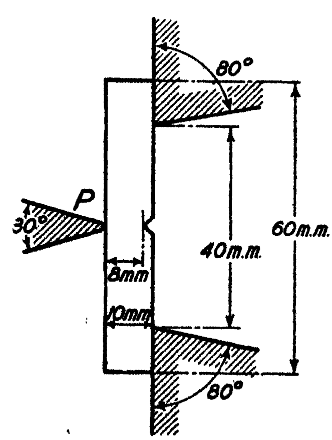


Fig. 25.—Charpy standard test-piece

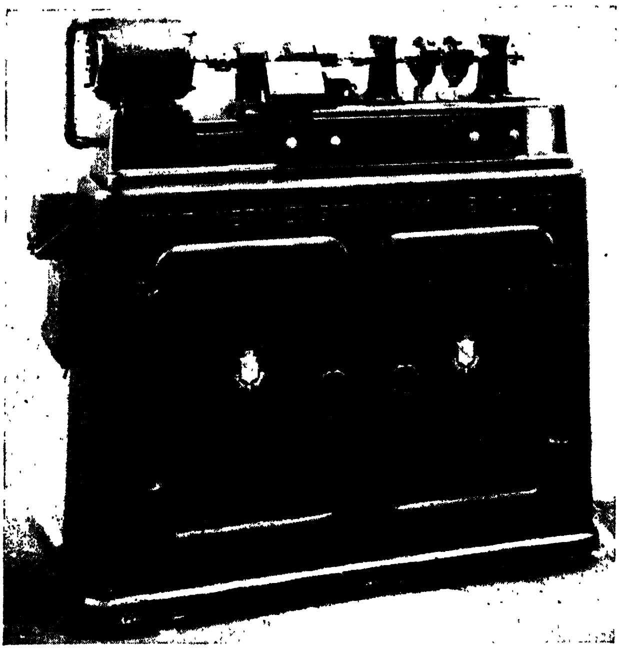


Fig. 26.—Rotating-beam type fatigue-testing machine

blow machines, the original Izod and Charpy machines are the best known. In principle and operation both these machines are simple. A falling pendulum with standard striking energy and velocity strikes a notched specimen either as a cantilever (Izod) or beam (Charpy). The work expended in breaking a notched specimen by a single blow is measured by the difference in the striking energy of the pendulum before and after impact.

The striking energy and striking velocity of the Izod and Charpy pendulums are :

Striking Energy

Izod . .	120 ft.-lb. (16·6 kg.-m.)
Charpy . .	30 kg.-metres

Striking Velocity

Izod . . .	3·5 metres per sec.
Charpy . . .	5·3 metres per sec.

The Test-piece

The dimensions of the notched-bar impact test-piece are important, and are standardised by the British Standards Institution.

Izod (*Cantilever type*) *Test-pieces.*—The standard notch is a vee-notch of 45° included angle, with a radius of 0·25 mm. at the bottom of the notch. The dimensions of this specimen, its

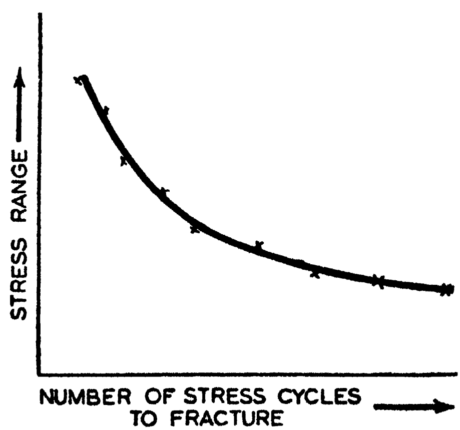


Fig. 27.—Endurance curve

position in the grips of the machine, and the angle at which it is struck are shown in Fig. 24.

Charpy Test-piece.—The Charpy standard test-piece and the method of supporting it in the machine are shown in Fig. 25.

The Izod machine is illustrated in Fig. 23. The specimen is held in the gripping dies, and as the pendulum falls the striking knife-edge strikes the specimen. The pendulum rises at the other side of the swing, the loose pointer indicating on the quadrant the number of foot-pounds absorbed by the specimen in fracturing.

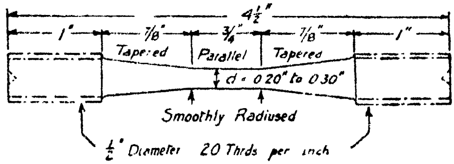


Fig. 28.—SPECIMEN FOR HAIGH ALTERNATING STRESS-TESTING MACHINE
(*Bruntons* (*Musselburgh*), *Ltd.*)

FATIGUE TESTING

Fractures Due to Fatigue

A large number of fractures that occur in practice are due to fatigue rather than to lack of static strength. Fatigue occurs in a material as a result of repeatedly applied stresses. The stress required to cause fracture by fatigue is usually much less than that to cause fracture due to static loading. Fatigue in metals is recognised by the fracture occurring in a brittle manner, even in the toughest and most ductile metals. Fine hair cracks are formed within the metal, and these spread gradually, as if the metal were glass-hard.

The kind of stress producing fatigue fracture may be tension, compression, or shear, or a combination of these. The range of stress is the algebraic difference of the stresses applied. The object of fatigue testing is to determine the fatigue limit (which may be defined as the maximum range of stress below which fracture will never occur due to fatigue).

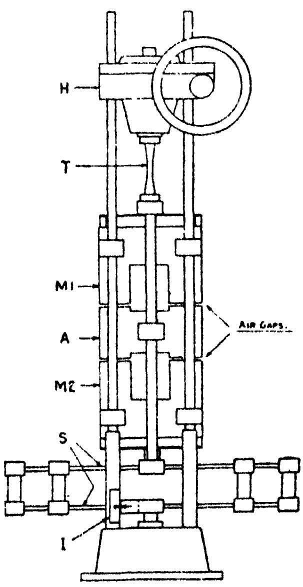


Fig. 29.—OUTLINE OF HAIGH ALTERNATING STRESS-TESTING MACHINE
(*Bruntons* (*Musselburgh*), *Ltd.*)

Rotating-beam Type Testing Machine

A number of machines have been devised for fatigue testing. Fig. 26 illustrates a machine for testing a specimen in the form of the rotating beam. Bending stresses are imposed on the specimen, which is rotated

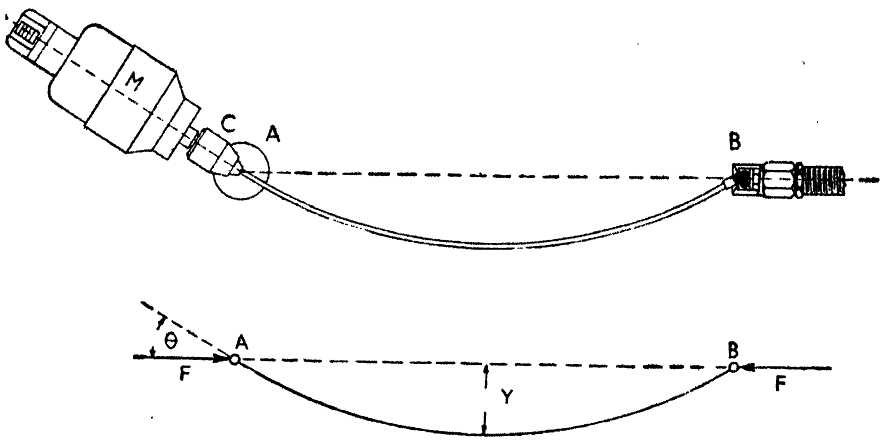


Fig. 30.—Principle of action of Haigh-Robertson fatigue-testing machine for wires. (*Bruntons* (*Musselburgh*), *Ltd.*)

by means of an electric motor. As the specimen rotates, the bending stresses change from tensile to compressive during each stress cycle, and any load may be imposed to give the required intensity of stress. An endurance test is carried out on a large number of identical specimens, which are tested under different ranges of stress until fracture occurs. If the results are plotted as shown in Fig. 27, the fatigue limit may be obtained. Some of the specimens in the test, being stressed below the fatigue limit, will never fracture.

Haigh Test

The Haigh alternating stress-testing machine is one which subjects a specimen of the form shown in Fig. 28 to alternate tensile and compressive stresses. In the machine outlined in Fig. 29, T is the specimen, A is the armature, which is supported between the electromagnets $M1$ and $M2$. These electromagnets are supplied with two-phase alternating current from a small electric alternator. When $M1$ attracts, $M2$ repels, and vice versa, with the result that A vibrates between them. Since the armature is connected to the lower end of the specimen, the vibrations are communicated to the specimen. The springs (S) serve to guide the armature rods, and initial tensile or compressive stresses may be imposed on the specimen. The stress intensity is read on the stress meter fitted beside the machine.

It has been found that corrosion has a great influence on fatigue, and numerous tests have been carried out to determine the relationship.

Tests on Wires

A special difficulty has to be overcome when making tests on wires. It is essential that the wires shall be gripped and loaded in such a manner

as not to affect the result of the test; the original surface of the wire must be left intact, since the removal of this would destroy the value of the test. A machine designed for this purpose is shown in principle in Fig. 30. One end of the wire is held in a chuck (*C*) as in the headstock of a lathe. The other end (*B*) is arranged to run in a thrust bearing, as a tailstock. The bending of the wire imposes stresses, and the sample of wire is kept rotating until it eventually fractures by fatigue, fracture occurring at or near to mid-span.

The results of a test on this machine are given below:

Specimen: Hawser wire 0·1 in. diameter. Ultimate tensile strength: 86·5 tons per square inch.

Five successive tests were made:

Bending stress applied, tons per square inch	28	27·5	27·0	26·5	26·0
Endurance, or stress cycles required to fracture, in millions	0·468	0·578	0·642	1·219	10·82*

* Specimen unbroken after nearly eleven million stress cycles.

From this set of tests it is seen that the fatigue limit lies between 26 tons and 26·5 tons per square inch, which is approximately only 29 per cent. of the high ultimate tensile strength of the wire.

CREEP TESTS

It has been found that no material is perfectly elastic, and a specimen loaded below its yield point will extend if the load is maintained for a considerable length of time. This "creep" is particularly noticeable at high temperatures, and creep-testing machines are used to give prolonged loading to specimens. Creep is measured over long periods of time by special extensometers.

When the specimen is loaded above the creep limit, it extends comparatively rapidly, the rate of this extension gradually decreasing, due to plastic strain hardening. The creep rate is then maintained at a nearly constant value for a period. Then the rate of creep again increases, until eventually fracture occurs. Special furnaces are made to completely enclose the specimen under test; the temperature of these furnaces can be controlled thermostatically, so as to maintain a constant temperature over a long period.

METALLOGRAPHIC TESTS

Examination under the Microscope

Metallography is the study of the structure of metals. It is a comparatively recent branch of metallurgical testing. It explains much about the behaviour of metals which would otherwise be obscure, and has helped to put their examination on a more rational and

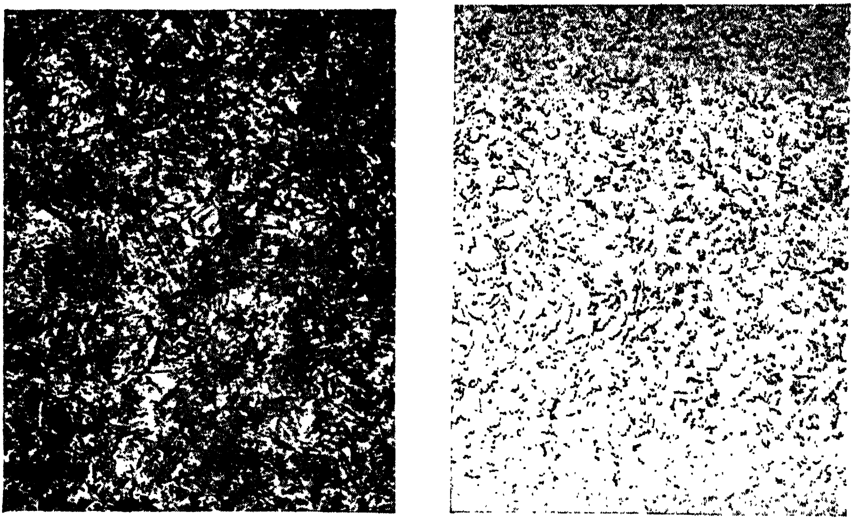


Fig. 31.—THE EFFECT OF HEAT TREATMENT ON THE STRUCTURE OF STEEL, AS SEEN UNDER THE MICROSCOPE

Left, the hardened condition. *Right*, the annealed condition.

therefore scientific basis. It is still growing, for the introduction of new combinations of metals means a further field for study and research.

Although to the unaided eye one piece of metal may look very much like another, the surface when suitably treated appears under the microscope as more or less regular and well-defined grains, crystals, or formations characteristic of the material, and often having a remarkable beauty of form and design. Defects or abnormalities in the metal, whether as a result of improper conditions of manufacture or harsh treatment during use, produce a corresponding change under the microscope, which to the trained eye tell an unmistakable story. The experienced metallurgist can often reach a conclusion from this evidence alone as to the cause of failure in service, and can suggest a remedy for the trouble.

Preparation of the Specimen

The surface of the specimen must be suitably prepared for examination, otherwise the best microscope in the world would fail to give any useful information. Unless due care is given to this stage of the operation, further work will be wasted. The steps involved may be set out briefly as follows :

(1) Cutting out the specimen or specimens from the mass of metal to be examined. The number and location of these will depend on the nature of the examination. In the event of a general examination being

advisable, numerous specimens will be required. They should be between $\frac{1}{4}$ in. and 1 in. across to give the best results, and the thickness between $\frac{3}{16}$ in. and $\frac{3}{8}$ in.

(2) Preliminary shaping and rubbing down of the specimen, prior to polishing. It is first filed with a fine file or ground wet on a slow-running grindstone, to produce a level surface. Edges and corners are then smoothed as far as possible to prevent damage to the polishing cloth in later stages.

The specimen is then rubbed face downwards, across a coarse emery paper, until the surface is completely covered with fine scratches parallel to one another.

Fig. 32.—AS SEEN UNDER THE MICROSCOPE

The normalised condition of a medium carbon content steel, free from alloying elements.

The same operation is repeated, using No. 1 emery paper, but in a direction at right angles to the first set of scratches. By using finer and finer emery paper in successive operations, finishing with No. 000 paper, the surface is gradually smoothed until it is ready for polishing. The change from one grade of paper to the next must not be made until all the previous scratches have been replaced by the new set.

Polishing the Specimen

(3) Polishing is effected by holding the specimen against a rotating disc soaked in water and coated with a polishing powder, the most suitable for general use being alumina. Proprietary brands can be bought for this purpose. Selvyt cloth makes a very good material with which to pad the disc, or, for iron and steel specimens, serge suiting cloth is excellent. For good results the specimen must never be allowed to become dry.

Heavy buffing or dry polishing must be avoided, because it produces an amorphous or " flow " layer, which merely covers up the fine scratches left by the emery, instead of removing them.

Soft metals, such as copper or aluminium, suffer particularly from this drawback. Care must be taken to avoid too vigorous polishing, the final stages being carried out with metal polish on selvyt or chamois leather, sometimes by hand instead of with a mechanically driven disc.

In all the operations so far described, great care must be used to avoid any overheating or excessive stress on the metal, for this may pro-

duce changes in the structure which would render the results of subsequent examination quite misleading. For cutting, a lubricant of soft soap may be used; for grinding, a slow speed and plenty of water are necessary; when rubbing down, a heavy pressure must be avoided; and so on.

Etching the Specimen

(4) Etching of the specimen, to reveal the structure of the metal, is the next step. The etching liquid eats away particular parts of the metal, first at grain boundaries, and then the more soluble parts elsewhere. The various constituents, whether crystalline or inclusions, being inclined at slightly different angles to one another, reflect the light in different directions and reveal themselves in various degrees of light and shade.

The etching liquid should be selected so that the attack proceeds as far as desirable in from ten seconds to two minutes. The following liquids are suitable for various metals:

Normalised and annealed carbon steels. Hardened and tempered carbon steels. Low alloy steels and cast iron.	A 2 per cent. solution of nitric acid or a saturated solution of picric acid in alcohol.

Austenitic manganese and nickel steels: 15 per cent. hydrochloric acid.

Stainless steels: 10 per cent. hydrochloric acid containing 10 per cent. of ammonium persulphate, freshly made.

Copper: 20 per cent. ammonia solution plus 10 per cent. of ammonium persulphate.

Copper and magnesium alloys: Alcoholic solution of ferric chloride containing hydrochloric acid.

Aluminium alloys: Aqueous solution containing 2 per cent. hydrofluoric acid and 5 per cent. of nitric acid.

Zinc and zinc alloy: Alcohol containing 1 per cent. of strong hydrochloric acid.

The above proportions are all by volume.

Mounting the Specimen

(5) After being etched, the specimen is washed in water, followed by alcohol, and allowed to dry. It is then mounted by embedding it in plasticine adhering to a glass microscope slide. The purpose of the plasticine is to permit the surface of the specimen to be mounted parallel with the slide. The levelling can be done with the aid of an accurately machined brass ring and a glass plate.

In the latest method of mounting, a moulded bakelite cylinder is used instead of plasticine. The polishing is carried out *after* the specimen has been mounted instead of before, the specimen being completely embedded in the bakelite, which is warmed in a special press to soften it. This method is very useful for small specimens, which are otherwise difficult to handle.

Other methods of mounting small specimens prior to rubbing down are to cast solder, Wood's metal, or sulphur round them in a plasticine mould.

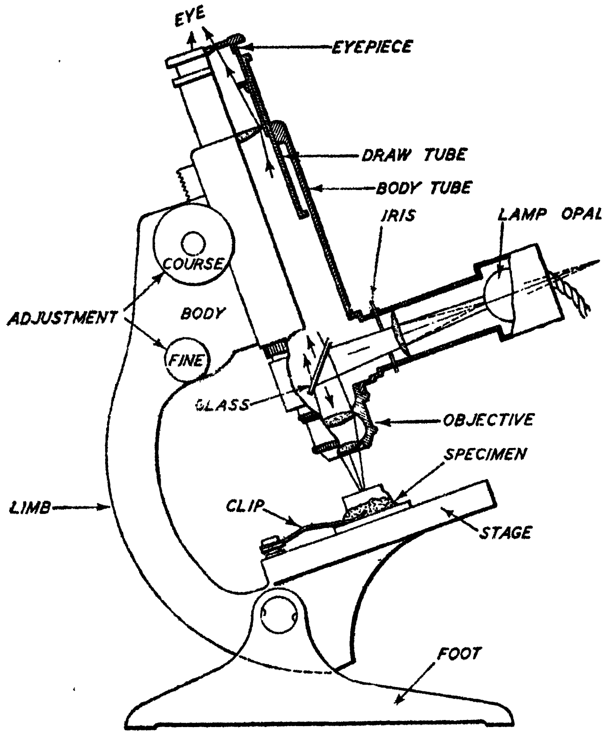


Fig. 33.—METALLURGICAL MICROSCOPE
Showing vertical illumination and other details.

Arrangement of Microscope and Illumination

We now come to the important subject of the type of microscope equipment and illumination best suited to the examination of metallurgical specimens. It is a subject on which whole books have been written, and all that can be done here is to indicate briefly the lines on which the expert microscopist works. Specially designed outfits can be purchased for this type of work, but the advanced operator often prefers to assemble his own apparatus, and only continued practice can produce results such as those shown in Figs. 31 to 35.

A microscope consists of a short-focus " objective " mounted at the lower end of the barrel and an " eyepiece " at the upper end. Objective and eyepiece consist of combinations of lenses cemented together to correct for colour and for curvature of the image. A set of objectives and eyepieces is required to give magnifications varying from 25 to 1,000 diameters, and occasionally up to 4,000 diameters.

Although the combined powers of objective and eyepiece determine the overall magnification obtainable with the microscope, it is upon the resolving power of the objective that the amount of detail which can be seen depends. By resolving power we mean the ability to separate small adjacent lines or particles. The eyepiece

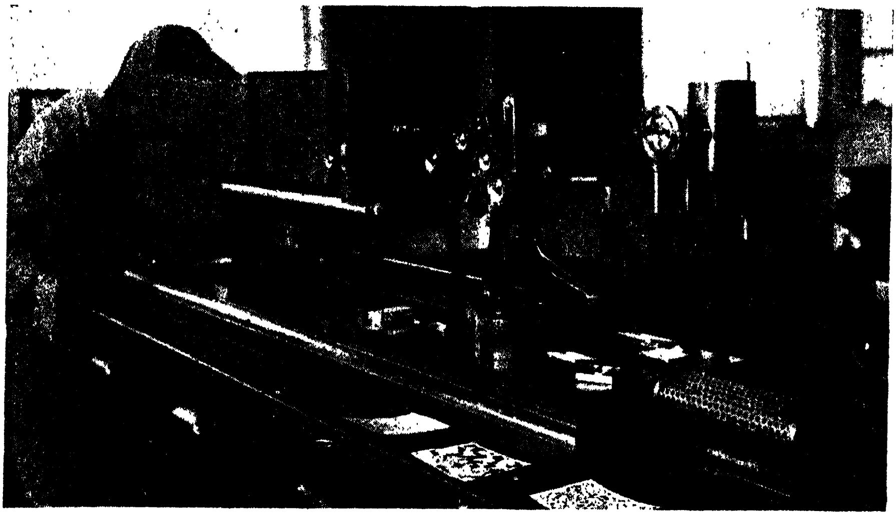


Fig. 34. TAKING A MICRO-PHOTOGRAPH
(*By courtesy of Thos. Glover & Co., Ltd.*)

merely helps to make visible the constituents which the objective has resolved.

The opaqueness of metallurgical specimens means that top or side lighting must be used to illuminate them instead of the bottom lighting used for thin transparent sections in bacteriology and in the examination of thin sections of mineral. Vertical illumination is by far the most usual kind, being the most effective and convenient. Different sources are used, according to whether a visual examination is being made or whether a photograph is to be taken. For visual examination an ordinary flashlight battery suitably mounted is very convenient, being small and easily fitted. For taking photographs, a much stronger light is required, in order to give a reasonable time of exposure. Either a carbon arc light is used or a "pointolite" lamp, which is an electric lamp with a very small and intense source. In each case, the rays of light must be passed through a condensing lens, followed by an iris diaphragm. The lens concentrates the light where it is wanted, and the diaphragm provides the necessary control over the area illuminated.

In Fig. 33 we get a good idea of how the vertical illumination is arranged. The light rays, passing through an aperture near the bottom of the barrel, are reflected downwards through the objective by an inclined glass slip on to the specimen, which reflects them up to the eyepiece. A glass prism, used in place of the slip, gives a brighter illumination, but reduces the resolution.

Micro-photographs

Fig.33 shows the focusing screws placed on the body of the microscope. When photographs are to be taken, however, the coarse focusing is effected by racking the stage of the microscope instead of the barrel. This arrangement avoids the necessity for disturbing the adjustment of the illumination.

For magnifications of 1,000 or more an oil-immersion objective is employed. Two drops of cedar-wood oil are placed on the specimen and one on the objective, and the stage racked up until the oil films meet. The oil must be free from air bubbles. (Caution : objectives must not be cleaned with alcohol or benzene. Use a well-washed silk handkerchief moistened with the tongue.)

For photographic work, an ortho-process plate is generally used in conjunction with a yellow or green screen. They are slow and give good contrast. Panchromatic plates are sometimes desirable.

ANALYTICAL AND CORROSION TESTS

These will not be considered in any great detail, as the former are usually made by specially trained chemists, and the latter concern chiefly the metallurgist who has to deal with metals used in chemical plant.

Determination of Carbon in Iron and Steel

The percentage of carbon in iron and steel has an important influence on the properties of these metals, and its determination is a routine test in many laboratories.

The apparatus used is fairly well standardised ; it consists of a heated refractory tube in which the carbon is burnt in a steam of oxygen. The carbon dioxide produced is absorbed in a specially designed weighed vessel containing potash solution or soda-lime. Sulphur dioxide and water vapour in the oxygen from the combustion tube must first be removed. An electrically heated furnace capable of giving temperatures up to 1,400° C. is the most convenient.

Determination of Sulphur

A commonly used method for the determination of sulphur in cast iron and ordinary steel consists of dissolving a weighed quantity of the steel in hot dilute sulphuric acid, and absorbing the sulphuretted hydrogen evolved in cadmium acetate solution.

The cadmium sulphide thus precipitated is filtered off, stirred with a measured excess of acidified iodine solution. The excess iodine is then titrated with sodium thiosulphate solution. From the iodine consumed, the sulphur content of the steel can be determined. This method has the

advantage of speed and simplicity, but for the high-duty alloy steels more elaborate methods must be used.

Standards for Analysis

It is worth mentioning that a whole range of carbon steels, alloy steels, iron, and non-ferrous alloys, etc., which have been carefully analysed by ten expert chemists, can now be obtained in the form of specially prepared samples. They are used as standards for checking metallurgical analysis and are particularly valuable to students.

Standardised pure reagents which can be bought in tablet form also simplify routine analysis, as they eliminate tedious preparation and measuring of solutions.

Corrosion Tests

Corrosion tests cannot usually be standardised, because they have to be adapted to reproduce the particular conditions of service of the metal —often a matter of some difficulty.

There are two tests, however, which have now become more or less standard. These are (i) the Salt Spray Test, which is useful for comparing the corrosion of metals and alloys, and (ii) the B.N.F. Jet Test for thickness of electro-deposits.

The *Salt Spray Test* is particularly valuable for quickly testing new formulæ for light aeroplane alloys in comparison with alloys which are known to be satisfactory in practice. An aerated spray of salt solution is blown on to the metal part in a cabinet at a controlled temperature by means of an electrically driven air compressor. The condition of the part, including loss of weight, etc., can then be examined.

In the *B.N.F. Jet Test* (Patent No. 476,876) an appropriate solution is allowed to drip upon the electro-plated surface through a calibrated jet at a constant rate. The time required to perforate the coating is measured. There are four solutions selected according to the metal, which can be nickel, copper, bronze, zinc, and cadmium electro-deposits, but not chromium.

Other Tests

Very few laboratories have facilities for testing all the properties which determine the suitability of metals for various purposes. There are numerous tests besides those already described, which, although they are not of a sufficiently routine nature to justify a detailed account in a brief review, may be mentioned briefly. They include, among others, physical properties, such as thermal and electrical conductivity, thermal expansion, magnetic properties, and melting-point; wear resistance, effect of heat treatment, response to hardening, X-ray analysis, amenability to the various processes to which metals are submitted during engineering operations, and spectrographic examination.

TESTING CEMENT AND CONCRETE

The wide and increasing use of concrete and ferro-concrete for roads, buildings, drains, sea-defence walls, and other kinds of structural work entitles this material to be regarded as one of the most important of modern engineering materials. Millions of tons of Portland and similar hydraulic cements are manufactured annually, each of which must be submitted to a variety of tests to ensure that they pass certain specifications drawn up for the protection of users.

Small users of cement rely on the manufacturers to supply cement of prescribed quality. They can do so with confidence, because the makers submit their products to regular tests, both to make sure it is up to standard, and for control of manufacture. Big users, especially where contracts for public works are concerned, either make their own tests or avail themselves of the services of consultants who specialise in this work, and provide an independent check on the tests made by the manufacturers.

In Great Britain the quality of Portland cement is governed by specification No. 12 (1931), prepared by a Committee of the British Standards Institution. This Association is an impartial body formed for the purpose of safeguarding users by laying down minimum requirements for many different kinds of products, and methods of testing. Government departments and scientific and industrial organisations are represented upon its various committees.

While the recommendations of the Association have no statutory or legal force, they are widely recognised as providing standards to which materials of good quality may be reasonably expected to conform. The American Association for Testing Materials (usually known as the A.S.T.M.) is the equivalent in the United States of our own Association, but does not prescribe quite the same tests or specify the same requirements.

Types of Cement Used for Structural Work

There are several kinds of cements used by the civil engineer for structural work, according to the conditions which have to be met. First of all we have the well-known Portland cement, which was first employed on a large scale for the Thames Tunnel in 1838.

The term denotes a particular variety of hydraulic cement generally made by burning limestone or chalk with clay and sand in proportions which must lie within fairly close limits. By far the largest proportion of cement being made is of this kind.

Rapid-hardening Portland cement is of the same class, and is made from the same materials, but is ground more finely to make it develop its strength more quickly. Where a job must be finished in a short time, to avoid delay and save expense, as in the case of important roads, rapid-hardening cement is often specified.

A recently developed but nevertheless important class of cement is aluminous cement. The well-known Ciment Fondu belongs to this class. Its special characteristic is the extreme rapidity with which its strength is developed ; it excels rapid-hardening Portland cement in this respect, although the ultimate strength is not so great.

Piles cast from concrete made from aluminous cement can be driven within twenty-four hours after the concrete has been poured—a big advantage where only a limited time can be allowed for a job. Aluminous cement also has a remarkable resistance to sulphate-bearing waters, sometimes a source of great trouble with Portland cements.

A third class of cement of importance in its own field is the so-called Portland blast-furnace cement, which is a mixture of ground Portland cement and blast-furnace slag. This cement is valuable for use for marine structures, such as sea-walls, because of its resistance to sea-water. Considerable quantities are used in Scotland and in Germany.

Pozzolana cements have been used for centuries and are still made where suitable raw materials occur. They are made by mixing naturally occurring active "pozzolana" earths, such as "trass," or burnt clays, with lime or with Portland cement. Their special attribute is their resistance to sea-water. They are not greatly used in this country.

Huge masonry dams erected during recent years in connection with irrigation and water-power projects have introduced special problems for the cement manufacturer. Large temperature rises occurring in these big masses of cement would upset its setting properties ; hence a modified form of Portland cement has been evolved. Special tests have been developed for these new low-heat cements, and, following the example set when the great Boulder Dam was erected, it will probably become usual in these big projects to issue specifications limiting the heat evolution.

Chemical Composition of Cement

Portland cement (so-called from a resemblance to Portland stone) is chiefly a mixture of silicates, aluminates, and ferro-aluminates of lime embedded in the amorphous glass from which they have crystallised during the cooling of the cement "clinker." A progressive chemical reaction between these compounds and water produces the setting and hardening on which the strength depends. Unless the proper proportions of lime, silica, and alumina are present in the cement, the balance of these compounds will be upset and the hydraulic properties of the cement will suffer.

Hydraulic Modulus

The British Standard Specification therefore stipulates that the proportion of lime divided by the sum of the proportions of silica and alumina (each being expressed as chemical equivalents—not in per cent. by weight) must not exceed 3 or be less than 2. This ratio is what is

known as the *Hydraulic Modulus* (or sometimes the "Lime Modulus"). To obtain the number of chemical equivalents, we merely divide the weight percentage of each substance by the molecular weight (56 for lime, 60 for silica, and 102 for alumina).

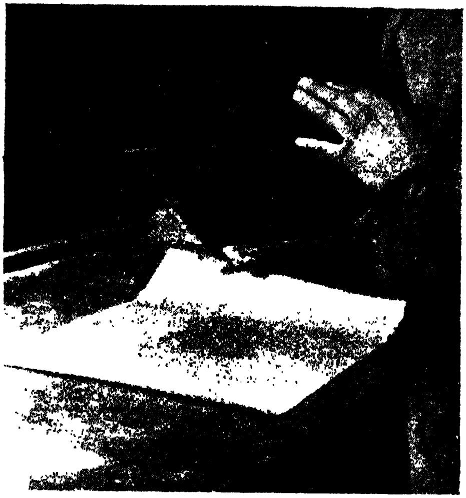


Fig. 35.—SIEVE TEST FOR CEMENT

Before the calculation is made, the percentage of lime present in the form of gypsum added to control the set must be deducted from the total lime. We need not go into this question in detail, because it primarily concerns the cement manufacturer, except to note the following ranges in composition in Portland cements marketed in this country:

	Per cent.
Lime	63–65·5
Silica	19–23
Alumina	4·5–8
Iron oxide	2–4·5

Aluminous cements contain very much more alumina (38–40 per cent.), much less silica (only about 5 per cent.), and have a lime content about equal to the alumina. There is no specified composition for aluminous cements.

Magnesia and Sulphate Contents

A high magnesia content may result in an unsound cement and cause a "delayed" failure a year or two after installation. The destruction of bridges, viaducts, and large buildings has been attributed to this cause. The specification therefore limits the magnesia content to 4 per cent.

A high sulphate content also causes unsoundness and cracking of the concrete by forming compounds which expand during setting. In this case the action is more rapid. The specification limits the content of sulphur present as sulphate to 1·1 per cent.

Fineness of Cement

The finer the cement, up to a point, the better it is able to combine with the water, and the greater the strength developed. The cement is therefore tested on two sieves: (*a*) the coarser, known as B.S. Mesh No. 72; and (*b*) the finer, known as B.S. Mesh No. 170. These sieves have 5,184 and 28,970 meshes per square inch, giving apertures 0·0082

and 0·0035 in. square respectively. Not more than 1 per cent. of the cement must remain on the former sieve after shaking for five minutes, or more than 10 per cent. on the latter after shaking for 15 minutes.

The sieves used for this test must have a surface area of at least 50 sq. in. and must be at least 2¾ in. deep. Circular sieves can be purchased with shoulders which enable them to be fitted together and to be provided with a lid, and with a pan at the bottom for receiving the finest cement.

With this four-tiered arrangement, the residues on both sieves can be determined simultaneously, by placing 4 oz. of the cement in the top compartment and shaking for fifteen minutes. The use of a shaking machine avoids the tedious manual labour and is desirable if many tests have to be carried out.

Determination of Cement Flour

Sieve tests do not give the fullest information about the size of the cement particles, because the most reactive portion of the cement is the finest part, considerably smaller in size than the smaller of the two sieve meshes.

To supplement the sieve tests, therefore, many laboratories determine what is often called the "flour" content, by floating off the very fine cement in a stream of dry air in a vertical tube in an elutriator. This test does not appear in the British specification, but is a valuable addition to the sieve tests. One commonly used type consists of a vertical brass tube 4 ft. high and 4 in. diameter, fitted with a cone at the bottom which contains the cement. The size of the particles blown off depends on the air speed. The air speed is regulated at an arbitrary value of 21 ft. per minute, which should remove particles of less than about 30μ. It should be pointed out that there is no special significance in this particular size. The test is, however, a useful one for comparing cements in the same apparatus.

Numerous other elutriators have been used, differing in their elaborateness, including one which uses petrol instead of air. Sedimentation tests for determining particle size are also used, and in some recent American specifications it is provided that the fineness must be determined by measuring the surface area in a turbidimeter by the Wagner method. This measures, by means of a photo-electric cell, the light scattered by the cement in suspension in kerosene when a beam of light falls upon it. The method is quick and simple, requiring only thirty minutes for completion, and is being used to an increasing extent in various forms.

Strength of Cements

The strength developed by the cement when set and hardened, either as a mortar in admixture with sand, or as a concrete in admixture with stones, gravel, or other "aggregate," is obviously of the highest import-

Fig. 36.—Wagner turbidimeter test for particle size determination

ance. In construction work, it is the strength under compression with which we are chiefly concerned, but unfortunately it is not very convenient to make satisfactory compression tests in the laboratory ; it is rather an elaborate business, especially where large blocks have to be tested, involving special mixing apparatus, compacting machines, and a large and powerful press. There is also the difficulty of standardising the aggregate required in large quantities.

For these reasons, some specifications, including the British Standard, contain not a compression test but a tensile test, on the assumption that the two bear a constant relationship to one another—an assumption which it is now realised is seldom justified. As a compromise, many European specifications include a compression test on a 1 : 3 sand mortar (cement 1 part, sand 3 parts).

Tensile Tests

The preparation and testing of the tensile test pieces is a comparatively simple matter, but to obtain reliable results the conditions, including water content of the mix, the temperature, degree of mixing, humidity of the atmosphere, and grading of the aggregate, must be standardised as closely as possible. At one time the British specification included a

Fig. 37.—PREPARING TENSILE BRIQUETTES

First stage.—Adding measured volume of water to weighed amount of sand cement mortar.

tensile test on the neat cement, but it is now realised that the results of this test have no real significance, and a 1 : 3 sand mortar is used instead.

The proportion of water used is such as to give an "earth-moist" consistency with the mixture of cement and sand, and is determined by a preliminary test, as described later on. It is usually about 8 per cent. by weight of the wet mixture.

The mixture of cement and special Leighton Buzzard testing sand is then gauged with water in the following way. The dry materials are mixed as intimately as possible on a flat steel or glass sheet, and then made up into a mound with a depression in the middle sufficiently large to receive the water. It is usual to prepare test pieces in triplicate for breaking after one, three, seven, and twenty-eight days, making a total of twelve test pieces, or briquettes, altogether, but it is best to make up only enough mixture for two briquettes at a time to obtain reproducible results.

Fig. 38.—PREPARING TENSILE BRIQUETTES

Second stage.—Gauging the "earth-moist" mortar.

The powder on the outside of the mound is then pushed gently into the water by means of a light-weight gauging trowel, taking care not to let more water escape from the heap than can be avoided. With the

Fig. 39.—PREPARING TENSILE BRIQUETTES
Third stage.—Filling moulds with moist sand cement mortar.

help of a second trowel the whole is then mixed together and as quickly as possible. A skilled gauger can complete this part of the operation in two minutes or so, but practice is needed to work up a uniformly moist mixture expeditiously. The temperature of the room must be between 58° and 64° F. during this operation.

The moist mixture is then filled evenly into a split brass mould of the form shown in Fig. 39, resting on a metal plate somewhat larger than the mould. The cement mortar is then compacted by beating, first on one side and then the other, with a standard spatula (also shown), until the mixture is level with the top of the mould. It is also a good idea to grip the plate and mould firmly in both hands and rap them smartly on the bench. To produce a satisfactory briquette, it is necessary to beat on a very rigid foundation—a half-inch thick steel plate firmly grouted to a brick or concrete pier makes the best gauging bench.

After smoothing off with a trowel, the mould and briquette are placed for twenty-four hours in a moist chamber in which the relative humidity is at least 90 per cent. They are then removed and "cured" by immersion in water until ready for breaking.

Quite a simple form of breaking machine suffices for measuring the tensile strength. The essentials are strong metal jaws to grip the test-piece and a means of applying the stress at the specified rate of 100 lb. per square inch of cross-section in twelve seconds. Lead shot running into a scale pan enables this to be done in a simple manner, the stream of shot being stopped automatically when the specimen breaks. As the cross-section of the neck of the briquette is a square inch, the weight of the shot multiplied by a factor for the machine gives the breaking stress in pounds per square inch.

The specified minimum breaking strengths at three and seven days after gauging are 300 lb. and 375 lb. per square inch respectively. The seven-day strength must show an increase over the three-day strength. Most Portland cements on the market easily pass this test, typical strengths

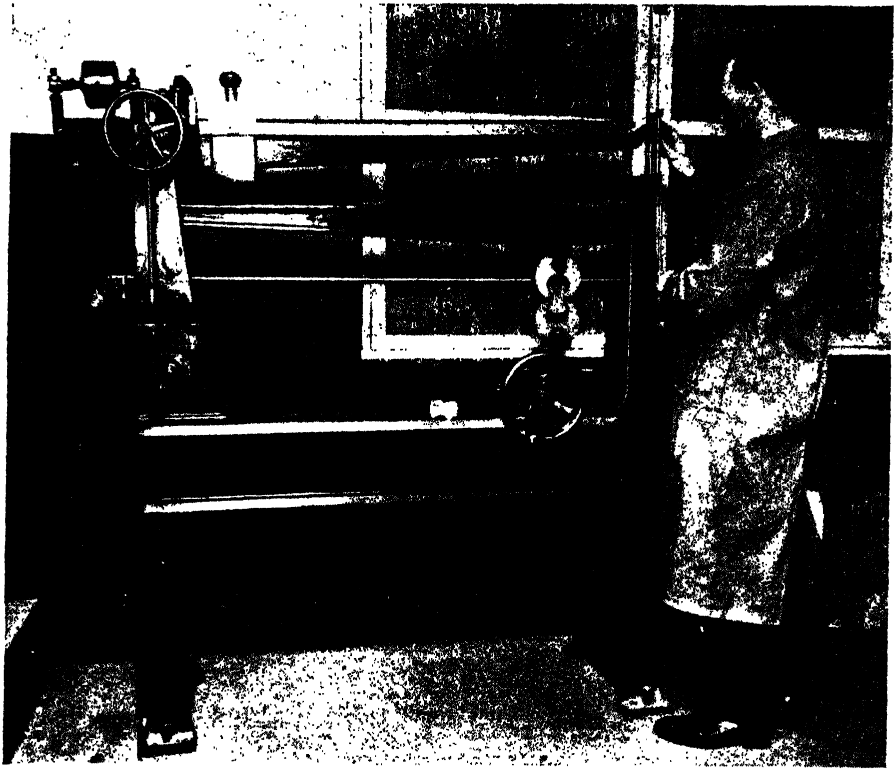


Fig. 40.—Breaking tensile briquette on a universal machine

for a good-quality cement being 525 lb. and 585 lb. per square inch at three and seven days respectively.

Compression Tests

The British Standard Specifications do not include compression tests, but they find a place in many foreign specifications, and give very valuable information, especially on concrete.

There are two usual kinds of compression tests : (*a*) on 3-in. cubes of 3 : 1 sand cement mortar ; (*b*) on 6-in. cubes of concrete, or on 8 in. by 4 in. cylinders, usually the former. The tests on concrete are described later.

Mixing of the sand cement mortar is often carried out in a Steinbruck Schmelzer mill, which consists of an edge-runner machine in which a heavy roller mounted on a horizontal axis rolls round in an annular trough, which itself rotates.

The compacting may be done by a Klebe hammer or a Boehme

hammer. In the former, a weight sliding in guides falls upon the upper surface of the mould at regular intervals a definite number of times. In the latter, the falling weight describes an arc of a circle at the end of a kind of tilt-hammer pivoted at one end.

Such a machine cannot easily be employed for filling the large moulds with concrete, and in this case the compacting is usually carried out by ramming the charge with a steel rod having a square end. The usual concrete mixture for testing purposes is 1 part cement, 2 parts gauging sand, and 4 parts graded gravel.

Fig. 41.—FILLING 6-IN. MOULD FOR COMPRESSION STRENGTH TEST ON CONCRETE

Compressive strengths can be considered good if they attain the following figures :

	Compressive Strengths in lb. per square inch			
1 : 3 *Sand Mortars :*	1 day	3 days	7 days	28 days
(*a*) Ordinary Portland	3,400	5,000	5,300	6,700
(*b*) Rapid-hardening Portland	3,800	6,500	7,000	7,300

Determination of Setting Time

In practice, sufficient water is added to the concrete or mortar to produce a wet mix. The cement begins to set as soon as the water is added, and if the setting takes place too rapidly, the mix may become difficult to work before the concrete has been properly placed, or may require the addition of excessive amounts of water to make it workable. Too slow a set is also undesirable.

Specifications therefore provide for the determination of two setting times—(*a*) the Initial Set, which indicates a partial loss of the plasticity of the gauged cement ; and (*b*) the Final Set, when the cement has begun to acquire an appreciable firmness. The tests are made on the plastic neat cement containing an amount of water found by a preliminary test (see next section). It must be understood, however, that the setting times so obtained are not necessarily those which are realised under the conditions of use, but experience shows that a cement which sets in the time specified gives good results in mortar and concrete. Nor must the setting of cement be confused with its hardening, which is a relatively slow process, involving rather different cement constituents.

Fig. 42.—VICAT APPARATUS FOR SETTING TIME
Note plunger at side to prevent too rapid fall of the needle.

Apparatus Required for Setting Time Determination

Setting times are determined by means of the Vicat apparatus, shown in Fig. 42. It consists essentially of (*a*) a cylindrical mould containing the setting cement paste ; (*b*) two weighted needles, one for the initial setting time and the other for the final setting time; (*c*) a slide supporting the needle; (*d*) a scale for measuring the depth to which the needle penetrates into the setting cement ; and (*e*) a stop-watch.

Initial Set

The cement is gauged with the proper amount of water in a manner similar to that employed when testing the tensile strength. With the aid of a trowel the Vicat mould (which must rest on a non-porous plate) is then filled with the cement paste, the top smoothed off, and the stop-watch started. As before, this operation must be performed at a temperature of 58°–64° F., and during the test the block must be kept in an atmosphere of 90 per cent. or over relative humidity.

To determine the initial set, the thinner of the two needles is secured in the holder, gently lowered into contact with the cement paste, and quickly released. At first, the needle sinks right into the soft cement, and after an interval of five minutes the operation is repeated at a different point on the surface, and so on until the needle fails to reach the bottom of the block. The time recorded by the stop-watch is then the initial setting time, which the British specification says must not be less than thirty minutes in the case of a normal-setting cement, or five minutes for a quick-setting cement.

Final Set

For the determination of the final set a differently shaped needle is employed. It is really a combination of the needle previously used and a circular plunger with a chamfered cutting edge. The needle stands proud of the edge of this attachment by 0·02 in. and the cement is con-

sidered as finally set when the needle makes an impression on the cement, but the circular cutting edge fails to do so. Sometimes a scum forms on the surface of the set cement, when the reverse side of the block may be used instead. The final setting time must not exceed ten hours for a normal-setting cement, or thirty minutes for a quick-setting cement.

Determination of Soundness

Le Chatelier Test.—All cements undergo some volume change during setting and hardening, but it is normally so small that no harm results. If, however, the cement contains too much lime or magnesia or is not burned sufficiently, or contains an excessive amount of sulphate, a relatively large expansion may occur, which causes cracks to appear in the concrete after an interval of weeks or months. The cement is then said to be unsound.

To detect unsoundness in a reasonable time in the laboratory, an accelerated test which hastens the hydration reactions must be employed. A number of such accelerated tests are used, the one prescribed by the British Standard Specifications being that known as the Le Chatelier test.

In this test the cement paste (gauged to the same consistency as for the determination of setting time) is contained in a flexible cylinder of thin brass, length and diameter 1·18 in., which is split to allow it to give to the expansion of the cement. Two needles 6·5 in. long attached to the cylinder on either side of the split magnify the expansion.

A small piece of glass covers one end of the cylinder while it is filled with the cement paste, and another piece of glass is then placed over the opposite end, where it is

Fig. 43.—Apparatus for Le Chatelier soundness test

Showing mould and heating bath.

kept in position by a small weight while the whole is immersed in water for twenty-four hours.

The distance between the indicator needles is then measured, and the mould replaced in the water. The latter is then brought to the boil and kept boiling for three hours. If, after cooling, the tips of the indicator needles have moved by more than 0·4 in., a fresh sample of cement powder must be aerated by exposure to the air for seven days and tested in a similar way. In this case the expansion must not exceed 0·2 in.

Pat Tests for Soundness

A pat test appears in the United States and several European specifications. It provides a useful addition to the Le Chatelier test and requires no special apparatus.

One gauges the cement into a stiffish plastic paste and fashions it into a circular pat on a thin sheet of glass. The pat has a diameter of about 3 in. and is $\frac{1}{2}$ in. thick in the middle, tapering off to a thin edge. After being stored in moist air for twenty-four hours, the glass with its adhering pat is then boiled in water for three to five hours. Any unsoundness shows itself in the appearance of bending or distortion of the pat, or cracking or disintegration. Detachment of the pat from the glass plate does not indicate unsoundness.

Determination of Normal Consistency

The quantity of water required for gauging the cement for the tensile strength test, the soundness test, and the determination of setting time is arrived at in the following way. Cement gauged with this amount has what is called "normal consistency."

A special needle 1 cm. in diameter, fitted to the Vicat apparatus already described, is used to determine the consistency. Pastes with different proportions of water are made up until one is found which allows the needle to penetrate into it to a point 5–7 mm. from the bottom of the mould. The time between the addition of water to the cement and the filling of the mould must not be less than three minutes or more than five minutes, or three minutes for a quick-setting cement. Seventy-eight per cent. of the quantity of water so found is the amount to be used for the setting time and soundness tests.

For the preparation of the sand cement briquettes for the tensile-strength tests, however, less water must be used, in order to give an earth-moist consistency. The following formula gives the percentage of water to be used in making these briquettes:

$$\tfrac{1}{4} P + 2{\cdot}50,$$

where P is the percentage of water required to produce the above-mentioned normal consistency.

Tests on Portland Blast-furnace Cement

A special British Standard Specification (No. 146) deals with Portland blast-furnace cements. In this type of cement the proportion of slag must not exceed 65 per cent., or the proportion of cement be less than 35 per cent.

The mixture of cement and slag, and the Portland cement part of the mixture, must pass the same mechanical tests as ordinary Portland cements, but there are one or two differences in the limits permitted in the chemical composition.

Tests on Concrete

A few years ago a special Committee of the Building Research Board prepared recommendations concerning the quality of concrete in reinforced concrete used in buildings. This "code of practice"[1] is based upon the best modern methods in concrete work, and may be regarded as a kind of unofficial standard specification.

The code provides that 6-in. concrete cubes shall be prepared for testing (*a*) in the laboratory, and (*b*) on the works site. As more careful control is possible in the former so-called "preliminary" tests, the minimum strengths specified are greater than in the works tests.

Fig. 44.—Slump test for concrete

In the preliminary tests, the water content of the mix must be as nearly as possible equal to that used in the actual work, but except in special circumstances must not be less than 30 per cent. by weight of the cement, plus 5 per cent. by weight of the aggregate. In the works tests, a sample of the wet concrete is taken for testing as it is being placed on the job.

The moulds are of steel or cast iron, with accurately machined faces and a flat leak-proof baseplate. The amount of ramming that the concrete receives in the mould in the preparation of the test cube depends on its consistency, as determined by a "slump" test described below. The concrete is placed in the mould in three layers; each receives thirty-five strokes of the bar if the "slump" is 1½ in. or less; or, for wetter mixtures, the number of strokes may be reduced to twenty-five.

[1] *Report of Reinforced Concrete Structures Committee of Building Research Board.* H.M. Stationery Office, 1*s*. 3*d*.

In the laboratory tests the cubes must be stored for the first twenty-four hours at 58°–64° F. in an atmosphere of at least 90 per cent. relative humidity, and then in water at the same temperature till required. Such strictly controlled conditions cannot be provided in the works tests; in this case the cubes are stored for the first twenty-four hours under damp sacks, and then in damp sand on the site for at least three-quarters of the period prior to testing. The temperature during curing must not fall below 40° F.

The code of practice recommends the following minimum cube strength at twenty-eight days for various grades of concrete in a 1 : 2 : 4 cement-sand-gravel mixture by volume:

	Preliminary Tests, lb. per sq. in.	*Works Tests, lb. per sq. in.*
Ordinary-grade Concrete	3,375	2,250
High-grade Concrete	4,275	2,850
Special-grade Concrete	4,750–5,980	2,850–3,560
	(according to permitted stresses)	

There should be no difficulty in obtaining these figures with concrete carefully made from good-quality cement.

Simple Test for Concrete

The consistency of the concrete has an important effect on its strength, and on the amount of the work required to develop that strength. The slump test controls the consistency, and is useful, not only in connection with strength tests, but for maintaining the proper consistency in the concrete during placing.

The slump is measured by filling a hollow truncated steel cone, dimensions 12 in. high by 8 in. diameter (bottom) by 4 in. diameter (top), with the concrete in four successive 3-in. layers. The cone has two handles and suitable foot pieces. Each layer is punned twenty-five times with a bullet-pointed rod $\frac{5}{8}$ in. diameter and 2 ft. long. The steel cone is then immediately removed; the extent to which the cone of concrete falls below its original height is called the slump.

A slump of $\frac{1}{2}$–1 in. corresponds roughly with the water required for maximum strength development, but is usually too stiff for most constructional work. The following table gives the recommended slumps for various classes of concrete, and the corresponding amount of water, expressed as a percentage of that required to produce a 1-in. slump.

	Maximum Slump (in inches)	*Approximate Water required (per cent.)*
1. Mass Concrete	2	105
2. Reinforced Concrete:		
(*a*) Thin Vertical Sections	6	125
(*b*) Heavy Sections	2	105
(*c*) Thin Confined Horizontal Sections	8	150
3. Roads and Pavements:		
(*a*) Hand-finished	4	107
(*b*) Machine-finished	1	100
(*c*) Mortar for Floor Finish	2	105

Chapter V

FUEL AND GAS TESTING

THE rising cost of fuel and labour has drawn attention to many aspects of economical fuel consumption that have hitherto been neglected even in fairly large concerns, and more attention is being given to problems affecting economic efficiency than ever before. Unfortunately, the thermal efficiency of fuel consumption and combustion can only be arrived at in a very roundabout manner, and this is probably the reason why so many fuel-consuming plants are being run at a cost well above what could be reasonably expected.

The most useful data upon which to assess the efficiency of fuel burning in steam-generating and other plants are the figures representing the calorific value of the fuel and the percentages of carbon dioxide and carbon monoxide in the waste gases. To obtain the former with great accuracy calls for considerable expert experience and expensive instruments, but extremely useful results can be obtained by any intelligent person sufficiently interested in the subject to give the matter a little time and consideration, and no matter whether the fuel consumer or the owner of a steam-generating plant adopts fuel and gas analysis or not, it is most desirable that he should be acquainted with the reasons for such analyses and the methods that can be adopted to obtain satisfactory and consistent results.

Fuel and the Calorimeter

The calorific value of a fuel is the quantity of heat a unit weight will give out when it is completely burnt and the products of combustion are cooled to the original temperature. This is usually expressed in British Thermal Units per lb., and may vary between 10,000 and 15,000 B.Th.U. in the case of coal.

To obtain the calorific value a calorimeter is used in which a prepared sample of the fuel is burned in a vessel containing water, and the comparison of the original and final temperatures of the water gives the calorific value. Many types of calorimeters are in use, one of the simplest and least expensive being the "Ronald Wild" bomb type illustrated in Fig. 1. This consists of a combustion chamber with a screwed cap suspended from a cover by a tube furnished with a valve. The water vessel is of plated copper and is surrounded by an outer casing, the annular space between the two vessels forming an air jacket which pre-

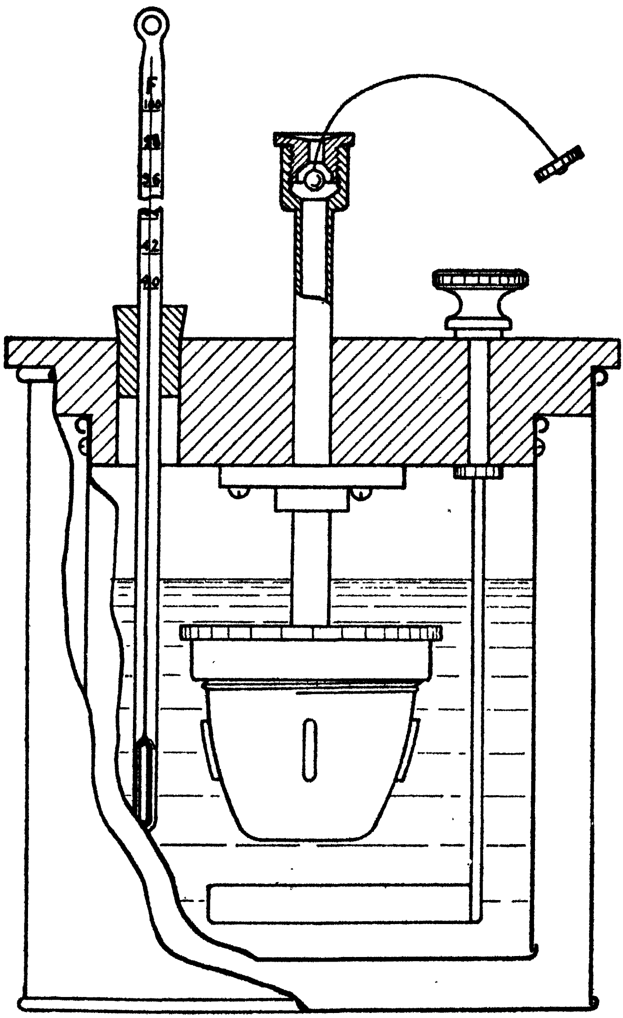


Fig. 1.—The "Ronald Wild" fuel calorimeter

vents radiation and absorption. An agitating paddle is provided for working in the water space and is manipulated from the outside of the cover. A Fahrenheit thermometer graduated 40° to 100° is provided, the scale being divided into tenths of a degree for easy reading to one-twentieth of a degree.

Operation of Calorimeter

The operation of the calorimeter is as follows: the sample of coal to be tested is carefully ground to pass through a sixty-mesh sieve or smaller and dried in an air oven at about 220° F. for one hour or until completely dry. Of the sample 0·73 gramme is weighed, mixed with 12 to 14 grammes of sodium peroxide, and transferred to the combustion chamber and the cap firmly secured. Water equivalent to 1,000 c.c. less the certified water value of the calorimeter is poured into the water vessel. The combustion chamber is placed in the water vessel and the thermometer inserted in the hole in the cover. The paddle is then agitated and the temperature of the water taken. A small piece of red-hot nickel wire is dropped down the hole communicating with the combustion chamber and the ball valve closed. The paddle is kept in motion for four to five minutes and the maximum temperature of the

water taken. The difference between the initial temperature and the final temperature multiplied by 1,000 is the gross calorific value of the fuel in British Thermal Units per lb.

Example.—Initial temperature, 51·5°; final temperature, 63·7°, then $(63{\cdot}7 - 51{\cdot}5) \times 1{,}000 = 12{,}200$ B.Th.U. Evaporative power, $12{,}200 \div 970{\cdot}7 = 12{\cdot}5$ lb. from and at 212° F.

Gross and Net Calorific Value

The gross or higher calorific value of a fuel includes the heat evolved in the formation and condensation of steam from free and hygroscopic moisture and from the moisture formed by the combustion of hydrogen. In the calorimeter all the steam loses its latent heat and the moisture its sensible heat to the initial temperature of 60° F. Higher calorific value is given as "dry" and "as received." The latter is usually taken as the standard.

Net or lower calorific value takes into account the free and hygroscopic moisture and also the moisture due to the combustion of hydrogen by subtraction. A determination of net calorific value calls for an ultimate analysis of the fuel, although the hydrogen content is often based upon the percentage of volatile matter in the fuel, the latent heat being taken as 1,055 B.Th.U. per lb.

CALORIFIC VALUE OF SOLID FUELS

Fuel	*Gross Calorific Value per lb.*		*Fuel*	*Gross Calorific Value per lb.*	
	Dry	*As received*		*Dry*	*As received*
	B.Th.U.	*B.Th.U.*		*B.Th.U.*	*B.Th.U.*
Straw . .	6,000	5,000	Coke . .	12,800	12,400
Oak bark .	6,000	4,000	Coke breeze .	11,000	10,000
Wood, dry .	8,000	6,000	Midlands coal .	12,600	11,500
Charcoal . .	13,000	12,000	Welsh smokeless	14,400	14,200
Peat, air dried .	9,000	7,000	Anthracite .	14,800	14,600

Proximate Analysis

A proximate analysis in addition to a determination of calorific value fixes the percentages of moisture, volatile matter, fixed carbon, and ash in the fuel.

Ultimate Analysis

An ultimate analysis in addition to the above determines the hydrogen, nitrogen, sulphur, and oxygen contents.

Fuel analyses, particularly the ultimate, are complicated and to be of value require to be carried out by an experienced chemist. For those

interested, a small book published under the authority of H.M. Stationery Office by Messrs. Harrison & Son, 44 St. Martin's Lane, W.C.2, at 9*d*., and entitled *Methods of Analyses of Coal*, can be recommended.

Gas Testing

In order to ascertain the loss of heat in the waste gases of combustion with great accuracy it is necessary to know the composition of the fuel, the weight of waste gases per lb. of fuel, and the initial and final temperatures. For most practical purposes the efficiency of combustion can be based upon the percentage of carbon dioxide in the gases and the final temperature. A simple formula for calculating heat losses is :

$$(t - 75)\ 2{\cdot}6\ (CO_2 + 0{\cdot}75)$$

where t is the final temperature.

As an example, let the gas temperature be 500° F. and the CO_2 7 per cent. Then $(500 - 75)\ 2{\cdot}6\ (7 + 0{\cdot}75) = 21$ per cent. loss.

If the percentage of CO_2 can be raised from 7 to 12 per cent. by careful attention to air supply and combustion conditions, the heat loss becomes :

$$(500 - 75)\ 2{\cdot}6\ (12 + 0{\cdot}75) = 12{\cdot}8 \text{ per cent.},$$

or a gain of $21 - 12{\cdot}8 = 8{\cdot}2$ per cent.

In practice, with the small plant, the percentage is seldom greater than 12 per cent. and should not drop much below 10 per cent. The percentage of carbon monoxide can be ascertained by means of the Orsat apparatus, but it is usually neglected as unlikely to be present with normal CO_2 readings.

The Orsat Gas-testing Apparatus

The Orsat apparatus is simple in use and with constant practice gives the highest degree of accuracy. The price is so low that it brings it within reach of the small fuel consumer, and while it is not so convenient as the fully automatic indicator or recorder, it can be strongly recommended for use in plants where the much more expensive automatic apparatus would be difficult to justify.

The complete apparatus can be obtained with two, three, or four absorption vessels, the type most frequently used being illustrated in Fig. 2. This is known as the "Orsat-Fischer," and consists of a case with a sliding back and front and containing a stopcock tube with four stopcocks ; a graduated burette with jacket ; absorption U tubes ; rubber bellows ; and absorption U tubes with copper spirals for cuprous chloride solution.

The measuring tube (A) contains from zero mark at the bottom to the upper capillary end exactly 100 c.c., but its graduation in ⅕ c.c. only extends to 40 c.c. and ceases where the tube is enlarged. In order to protect the gas which is contained in this burette from the influences of the changes in temperature externally, the tube is surrounded by a

water jacket, closed at the top and bottom by india-rubber stoppers and provided with a white background of opaque glass upon which the black divisions of the burette are plainly visible. The bottom of the burette is connected by a rubber tube with a level bottle (B) filled two-thirds with water; the top end is connected to a glass capillary (A) bent at right angles and ending in a three-way cock. This tube is protected against breaking by a wooden frame, and carries at a right angle three taps h', h'', h''', each provided with a capillary tube and connected by india-rubber joints with the three U-shaped absorption vessels C', C'', C''', filled with bundles of glass tubes. The first of these is filled with a solution of caustic potash, the second with an alkaline solution of parogallol, the third with a concentrated solution of cuprous chloride in hydrochloric acid. In order to keep this solution in an unchanged state it is left in constant contact with copper spirals, introduced into the glass tubes with which the vessel C'' is filled.

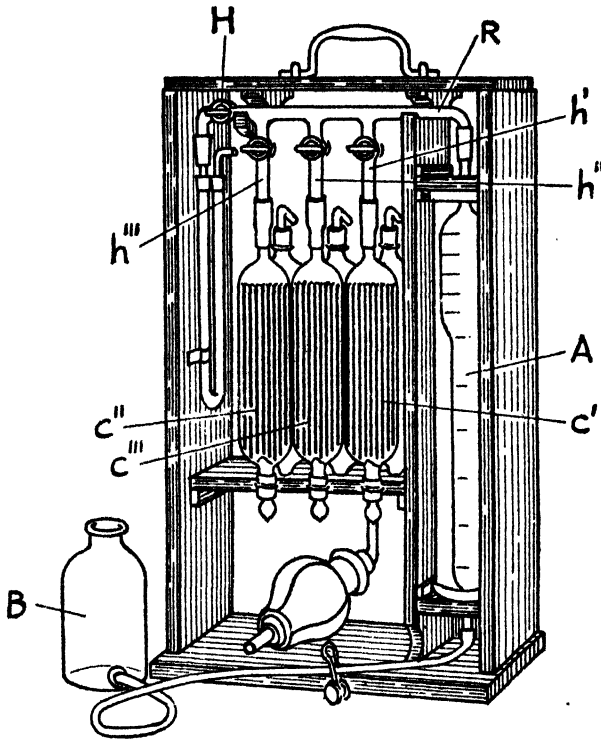


Fig. 2.—THE "ORSAT-FISCHER" GAS-TESTING APPARATUS

The absorption vessels are filled with water slightly more than half-way up, and this is drawn up to the mark made in the capillary neck by opening the connecting tap and running off the water contained in the burette (A), for which purpose the levelling bottle (B) must be lowered. In order to protect the absorbing solutions against action of the air, the outer ends of the vessels are closed by small balls of thin rubber.

Manipulation

To obtain a sample of gas a length of iron or copper tube is inserted into the flue of the boiler with the inlet end as near as possible in the

centre of the gas flow. This tube is then connected to the testing apparatus and a sample of the gas is drawn into the sampling tube either by means of a rubber bellows or a small hand-pump. The procedure is then as follows. Raise the level bottle (B), open the tap, and allow the burette (A) to fill with water up to the capillary part. Now aspirate the gas by lowering the level bottle and turning the tap through 90°. Run off the water a little below the zero mark and close the tap, compress the gas by raising the level bottle till the water rises above zero, squeeze the connecting rubber tube close to the joint, and then, after lowering the level bottle, allow the excess of water to run out to zero by cautiously loosening the rubber tube. Last of all, the tap is opened for an instant in order to produce a pressure equal to the atmosphere, whereupon exactly 100 c.c. of gas will be confined within the burette.

Now the absorption begins, first that of the carbon dioxide by conveying the gas into the U tube C'. This is done by raising the level bottle and at the same time opening the tap h'. The absorption is hastened by causing the gas to travel several times from C' to A and back, alternately lowering and raising the level bottle, leaving the tap h' open all the time. At last the level of the liquid in C' is adjusted to the mark, and the tap h' is closed. Now the reading can be taken, after raising the level bottle till its contents are at the same level as the water within the burette. The decrease in volume indicates directly the percentage by volume of carbon dioxide. In exactly the same way the oxygen is absorbed in C'' and the carbon monoxide in C''', the unabsorbed residue representing nitrogen.

Percentage of Heat Losses in Waste Gases with Various Percentages of CO_2

CO_2 Per Cent.	*Temperature of Waste Gases, Degrees Fahr.*				
	400°	500°	600°	700°	800°
12	9·8	12·8	15·8	18·8	21·8
11	10·6	13·5	17·1	20·4	23·7
10	11·9	15·2	18·7	22·3	25·8
9	12·8	16·7	20·7	24·6	28·6
8	14·2	18·6	23·0	27·4	31·6
7	16·1	21·0	26·0	31·0	35·9
6	18·5	24·2	29·0	35·6	41·3
5	21·8	28·4	35·1	41·8	48·8

Excess Air

If it were possible to consume ordinary bituminous coal with the maximum efficiency by using the minimum theoretical quantity of air required to support combustion, the proportion of carbon dioxide appearing in the waste gases would be approximately 18·5 per cent.

In practice this is found to be impossible, but the nearer this figure is approached, in the absence of carbon monoxide, the better the combustion conditions and the higher the efficiency.

To find the percentage of excess air, knowing the amount of CO_2 in the waste gases, let 18·5 per cent. be the theoretical CO_2 and 7 per cent. the actual, then :

$$100 \times \frac{18{\cdot}5 - 7}{7} = 164 \text{ per cent.}$$

If the actual CO_2 can be increased from 7 to 12 per cent., the percentage of excess air will be reduced to $100 \times \frac{18{\cdot}5 - 12}{12} = 54$ per cent., a difference of $164 - 54 = 110$ per cent.

Notes on the "Ronald Wild" Calorimeter

It is essential that the interior of the crucible and its contents should be absolutely dry, and that the screwing up of the crucible to its cover should render it perfectly sound against the entry of water when submerged. Otherwise the presence of moisture in the crucible may generate a greater pressure than the apparatus will withstand.

Sodium Peroxide.—This should be of high grade, though chemically pure compound is not essential. More important is its physical state, which should be in powder form to make an intimate mixture with the fuel sample. The stock of peroxide should be kept in an airtight container and opening and closing the container should be done as quickly as possible. Absorption of water vapour and CO_2 from the atmosphere vitiates the activity of the sodium peroxide and leads to difficulty in firing.

When the fuel contains a large amount of ash it is sometimes difficult to ignite when mixed with the normal amount of sodium peroxide, and this has to be reduced in quantity. For example, with 10 per cent. ash 13 grammes is a good proportion, 15 per cent. ash 12 grammes, 20 per cent. ash 11 grammes, and 25 per cent. ash 10 grammes, the object being to have the sodium peroxide from sixteen to twenty times the weight of the combustible part of the fuel.

Electrical Firing.—This can take the place of the red-hot nickel wire, and is done from a 4-volt accumulator of about 5 amps. continuous, with a fuse of the wire provided with the instrument. Coke, being less inflammable than coal, is more difficult to ignite, and a thicker wire should be used, so as to retain its heat for a longer time.

The results obtained from fuel samples containing an appreciable percentage of hydrogen will be low on account of the thermal reactions of hydrogen with sodium peroxide being less than those of carbon. For this reason the weight of sample to give direct reading of calorific values should be corrected for hydrogen content according to a table provided.

Notes on the Orsat Apparatus

The apparatus should be kept clean and the joints air-tight.

Absorbent solutions must be renewed when they become weak.

The water in the apparatus should be saturated with carbon dioxide before a test is taken.

Samples of gas can be drawn into collecting jars and the test carried out at a convenient time away from the gas chamber or the apparatus may be connected directly to the sampling tube of the gas chamber.

If the former method is adopted, it is important that representative samples should be obtained under various working conditions.

Consistent and reliable results will only be obtained by regular and constant use.

Chapter VI

TESTING LUBRICATING AND FUEL OILS

THE rapid progress made in many phases of engineering development in recent times is due in no small part to the improvement made in lubrication and fuel oils during the past few years. The efficiency and reliability of the modern Diesel engine, the Aero engine, and the steam turbine, to mention only three examples, are largely the result of a better understanding of the principles involved in this connection. The wide range of oils available to-day is the result of a vast amount of work carried out by the combined activities of petroleum technologists, chemists, and engineers.

The Properties of Oils

When an oil is selected for any given purpose, the properties of the oil, such as its density, viscosity, flash point, oiliness, etc., have to be chosen to suit the conditions under which the oil is to be used. Apparatus has been designed to test these various properties, and it is the purpose of this article to put before the reader a representative selection of such apparatus, the method of using it in the testing of oils, and an outline of the general properties required for certain purposes.

Sources of Oils

Oils may be (1) animal; (2) vegetable; or (3) mineral. Examples of animal oils are: lard, sperm oil, tallow, etc. The fat or oil is extracted from the body of the animal or fish under pressure by steam. Vegetable oils include olive, castor, palm, colza, linseed, etc. These oils are removed from the seeds by either a pressing process or by means of solvents. The mineral oils which form by far the largest quantities used are derived from petroleum sources and are separated by distillation.

Many of the animal and vegetable oils are unsuitable for lubricating purposes, as they are subject to gumming or rapid oxidation. These are largely used for painting oils, where the drying and thickening properties are of value.

Compounded oils consist of blends of mineral oils with small quantities of animal or vegetable oils.

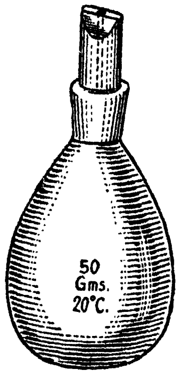


Fig. 1.- SPECIFIC GRAVITY BOTTLE

How an Oil Lubricates

The question is sometimes asked, "Why is a lubricant necessary ?" This question will be dealt with briefly before going into the matter of the actual testing. If two dry metal surfaces are rubbed together there is friction between them. If the surfaces are very rough, this friction is high, due to the projections of the surfaces rubbing over each other.

It might be thought that if the surfaces are polished, friction will thus be eliminated. In practice, however, it is observed that, if the surfaces are given a very high polish, the friction becomes much greater, due to the attraction between the particles which are pressed together. This attraction is so great that the particles "seize" or become practically welded together. Thus when seizure takes place it does so because the two surfaces are so close together that no air or grease separates them.

The purpose of a lubricating oil is to keep the surfaces apart by forming an oil film between them and thus preventing actual metallic contact. So long as this condition is maintained, the surfaces cannot seize. When the film between the surfaces is unbroken, the frictional resistance is due to the fluid friction of the oil particles, and the " thicker " the oil the greater is this fluid friction. The pressure forcing the surfaces together tends to squeeze out the oil film from between them, and the " thinner " the oil the more easily is this done. The oil therefore should be " thick " enough to prevent the film being broken, but not " thick " enough to cause excessive fluid friction. If movement between the surfaces ceases, the oil is squeezed out, as it is the relative movement of the surfaces which sets up and maintains the oil film. Thus the bearing pressure and speed have to be taken into account when selecting a lubricant.

The friction in a bearing generates heat and thus causes the temperature of the bearing and lubricant to rise. This rise in temperature causes the oil to become " thinner," and care must be taken to ensure that the oil is thick enough at the working temperature to prevent rupture of the film.

Oils working in high temperatures, like steam cylinder oils, which are used in conjunction with superheated steam, are very " thick " at normal room temperature, whereas refrigerator oils, which work at low temperature, are very " thin " at normal temperatures.

Testing of Oils

The object of testing oils may be either to determine the suitability of an oil for a given purpose or to see if the oil conforms to necessary specification.

An obvious method of testing an oil is to subject it to the exact

conditions under which it will work in practice and carefully note its behaviour over a long period. A short test of this description may be very misleading.

The usual tests carried out are as follows:

Specific Gravity

The specific gravity is equal to the ratio of the weight of a given volume of oil to the weight of the same volume of water.

$$\text{Therefore } Sp.\ Gr. = \frac{\text{Weight of given volume of oil}}{\text{Weight of same volume of water}}.$$

The standard temperature at which this test shall be made is 60° F.

The specific gravity may be determined by using a specific gravity bottle (Fig. 1) or a hydrometer.

The method of using the specific gravity bottle is as follows. The bottle is carefully cleaned and dried and then weighed. It is then filled with distilled water, care being taken to see that it is completely full, and again weighed. The difference between the weighings gives the weight of water. The bottle is then emptied of water, dried, and filled with the oil. This is then weighed. Again the weight of oil is found by difference. Since the same volume of oil and water have been weighed, the specific gravity of the oil is $= \frac{\text{weight of oil}}{\text{weight of water}}$.

The hydrometer consists of a glass float weighted at the lower end with a graduated scale at the upper end. This instrument is placed in the oil and the specific gravity is read on the scale at the level of the oil.

The lower the specific gravity of the oil, the lower will the hydrometer sink in the liquid. Sets of hydrometers are usually supplied in cases as shown in Fig. 2. Each hydrometer in the set deals with a fairly small range of densities, the nine hydrometers shown in the illustration cover specific gravities from 0·650 to 1·100 with a range of 0·05 each.

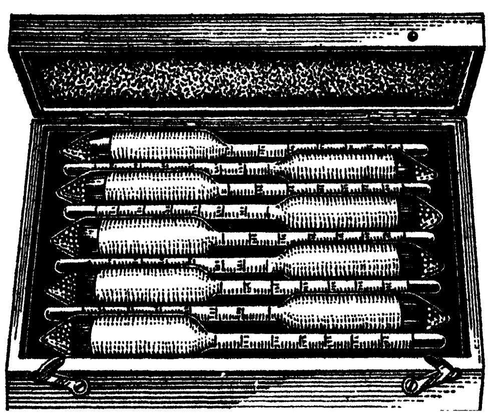


Fig. 2.—SET OF HYDROMETERS

The hydrometers in the set shown cover a wide range of densities.

Heating an oil causes it to expand, therefore to become less dense and to have a lower specific gravity, while cooling has the opposite effect. If it is not convenient to test the oil at 60° F., the specific gravity may be corrected by adding or

subtracting 0·00035 according to whether the test temperature is above or below 60° F. For example, if the specific gravity of a certain oil at 100° F. is 0·8800, then at 60° F. its specific gravity will be 0·880 + (100 × 0·00035) = 0·880 + 0·035 = 0·915.

If two oils with different specific gravities are mixed, the specific gravity of the mixture can be calculated from

$$Sm = \frac{V1S1 + V2S2}{V1 + V2}$$

When Sm is the specific gravity of the mixture
$S1$,, ,, ,, ,, ,, No. 1 oil
$S2$,, ,, ,, ,, ,, No. 2 ,,
$V1$,, ,,volume of No. 1 oil
$V2$,, ,, ,, ,, No. 2 ,,

The specific gravity of lubricating oils varies from about 0·86, and of fuels from 0·65 approximately to 1·0.

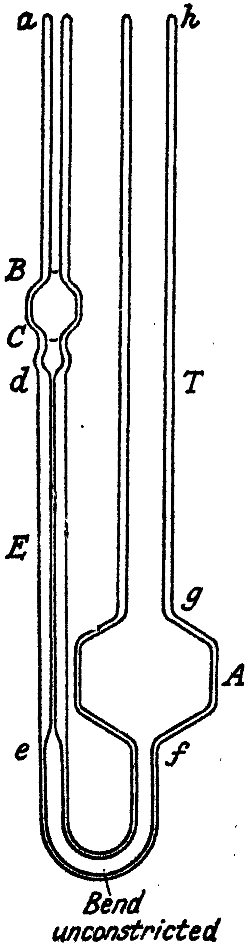


Fig. 3.—A U-tube viscometer

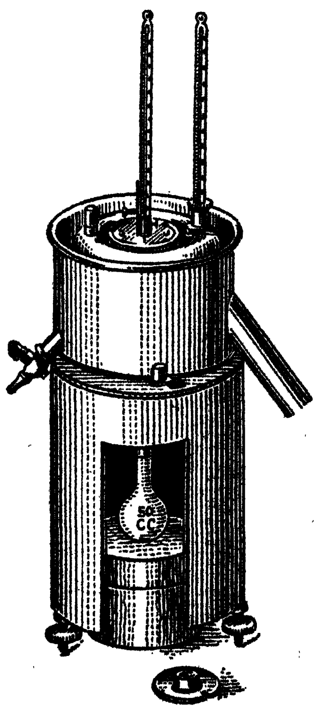


Fig. 4.—The Redwood viscometer

Viscosity

Viscosity is the name given to the "body" or "thickness" of a liquid. The importance of this property has already been mentioned. The instrument for determining this property is called a v i s c o m e t e r. A U-tube viscometer is shown in Fig. 3. A given volume of oil is placed in the bulb A down the tube T, and this is sucked up the small capillary tube E. The oil-level is adjusted to the point B and the oil is then allowed to flow back through the capillary tube under its own head. The time for the oil-level

to fall from B to C is taken, and from this time the viscosity is calculated.

The Redwood viscometer is the instrument used commercially in Britain (Fig. 4). It consists of a cylindrical vessel with an agate jet in the centre of the base which is closed by a ball valve. Surrounding the oil vessel is a jacket in which water or oil can be placed for maintaining a constant temperature. A copper tube closed at the lower end projects from the side of this jacket and a Bunsen burner may be applied to heat the contents and to keep the temperature constant. Thermometers are fixed in the oil vessel and the jacket. An agitator is used to mix the liquid in the jacket to ensure even temperatures.

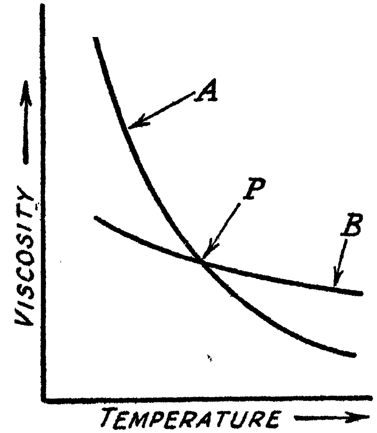


Fig. 5.—SHOWING THE VARIATION OF VISCOSITY WITH TEMPERATURE

The viscosity of the oil A falls rapidly with rise of temperature, but the oil B shows a much smaller change of viscosity over the same temperature range.

The method of carrying out the test is as follows. Oil at the required temperature is poured into the vessel to the height of a hook gauge inside. The temperature is checked and the ball valve is lifted, allowing the oil to flow through the jet into the glass vessel placed below. This vessel has a capacity of 55 c.c., and the time is taken for that quantity of oil to flow through the jet, the time in seconds giving the viscosity of the oil in " Seconds Redwood."

For very " thick " oils this test would take a long time, and a similar apparatus with a larger jet, called a No. 2 Redwood viscometer, is used, the time of flow using this instrument being one-tenth the time of the No. 1 instrument with the same oil.

The Engler viscometer is used on the Continent, and the Saybolt viscometer is used in America. These are similar in principle to the Redwood, the only difference being in their dimensions.

We have previously seen that the viscosity of an oil depends on its temperature. The temperatures at which the standard test is carried out are usually taken as 70° F., 100° F., 140° F., 200° F., but higher or lower temperatures may be used for special oils.

Graphs may be plotted showing the variation of viscosity with temperature. Fig. 5 shows two such curves plotted on the same base. At low temperatures the oil A is very viscous. The viscosity of this oil, however, falls rapidly with rise of temperature, so that at high temperature it is very "thin." The oil B, however, shows a much smaller change of viscosity over the same temperature range. At temperature P both oils have the same viscosity. This variation of viscosity with

temperature is of importance when dealing with oils for internal-combustion engines. To give easy starting-up from cold, to ensure rapid distribution of oil to the various parts, and to minimise fluid friction a low-viscosity oil is used, while to ensure that the oil film remains unbroken under working conditions of high temperature and pressure and to prevent leakage, care must be taken to select an oil with a fairly "flat" curve. The lubricating oil in an engine may suffer dilution due to mixing with the fuel oil, and this "thinning" during running must be allowed for.

Flash Point

When an oil is heated it gives off vapour, and as the temperature rises the rate at which vapour is given off increases. When the vapour is given off in sufficient quantities, it can be ignited by applying a small flame near the surface of the oil.

The lowest temperature at which this "flash" occurs is called the flash point. If the oil is heated in a closed vessel the vapour cannot get away as it is formed, whereas if heating takes place in an open vessel the vapour can escape. Thus the "closed flash point" is lower than the "open flash point." For lubricating oils the open flash point is from 20° F. to 40° F. higher than the closed flash point.

The Pensky-Martens apparatus is used for oils with flash points above 120° F. Fig. 6 illustrates this apparatus. It consists of an oil cup fitted with stirrers for the oil and vapour. A line inside the cup indicates the level to which the cup must be filled with the oil. The cup is surrounded by an air bath, which is heated from below by means of a gas or oil burner or by electricity. A cover fits on the cup carrying a sliding shutter, which can be

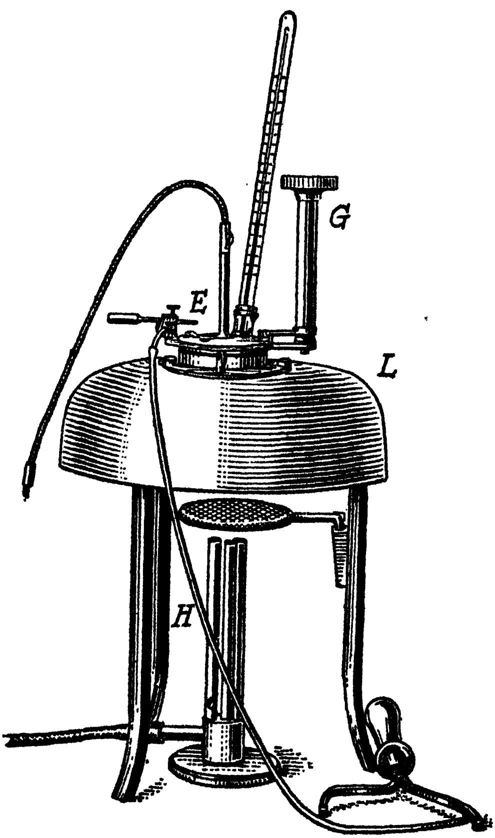


Fig. 6.—The Pensky-Martens apparatus for finding flash point of oils above 120° F.

opened to apply the small test flame. A thermometer passes through the cover into the oil cup.

The closed flash point is found by heating the oil in the cup so that the temperature rises between 9° and 11° F. per minute. The stirrer is turned at sixty revolutions per minute. The test flame is applied at intervals of 2° F. rise in temperature below 220° F. and at intervals of 5° F. above 220° F. A note is made of the temperature at which a distinct flash is seen on the surface of the oil when the test flame is applied.

The open flash point may be found by removing the cover and stirrer and fixing the test flame and the thermometer by means of a clip on the edge of the oil cup. Heating is at the same rate as before, and the temperature at which the first flash occurs is the open flash point.

The Fire Point or Fire Test

The fire point is found by heating the oil to a higher temperature until it continues to burn for five seconds.

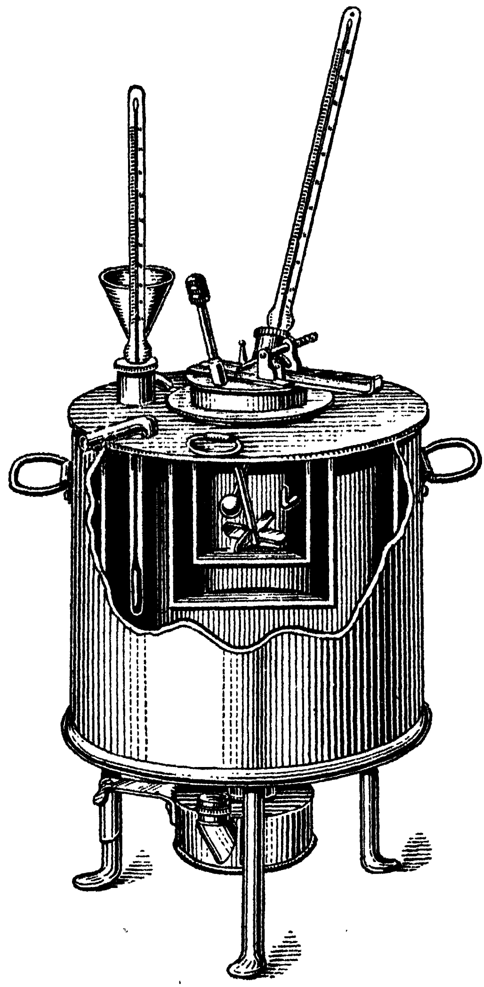


Fig. 7.—THE ABEL APPARATUS USED INSTEAD OF THE PENSKY-MARTENS FOR OILS WITH FLASH POINTS BELOW 120° F.

The *Abel* apparatus is used instead of the Pensky-Martens for oils with flash points below 120° F., such as some fuel oils. Fig. 7 illustrates the instrument, showing some of the internal parts.

Fuels like petrol have very low flash points, and these tests are often performed to satisfy legal requirements regarding oil storage.

If two oils having different flash points are mixed, the flash point of the resulting mixture may be found from $F = \frac{CW1F1 + W2F2}{CW1 + W2}$.

Where $W1$ and $W2$ are the respective weights of the oils 1 and 2, $F1$ and

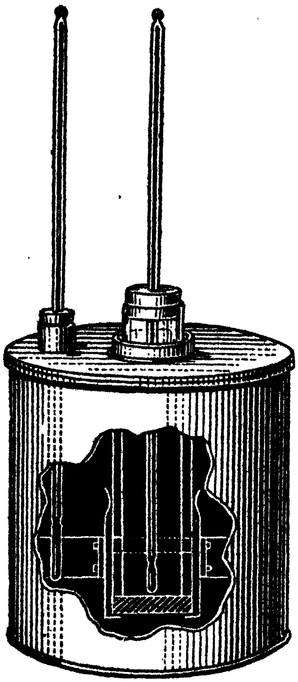


Fig. 8.—Apparatus for Testing Cloud and Pour Points

$F2$ are their respective flash points and C is a constant which varies with the oils mixed, being about 0·9 for Russian and 0·4 for American oils.

Volatility

The readiness with which an oil loses weight by evaporation is its volatility. A fuel oil should be fairly volatile so that it is readily converted into vapour, but lubricating oils should normally have a low volatility.

To carry out the test a standard quantity of oil is placed in a standard vessel and heated at 100° F. for a definite time. The oil remaining is weighed and the loss of weight expressed as a percentage of the original quantity gives the volatility.

Cloud Point ; Pour Point

It has been pointed out that as the temperature of an oil falls it becomes " thicker."

Fig. 8 illustrates the apparatus used. In the centre is the vessel containing the oil sample with a thermometer immersed in the oil. The outer vessel forms a jacket which contains a cooling mixture.

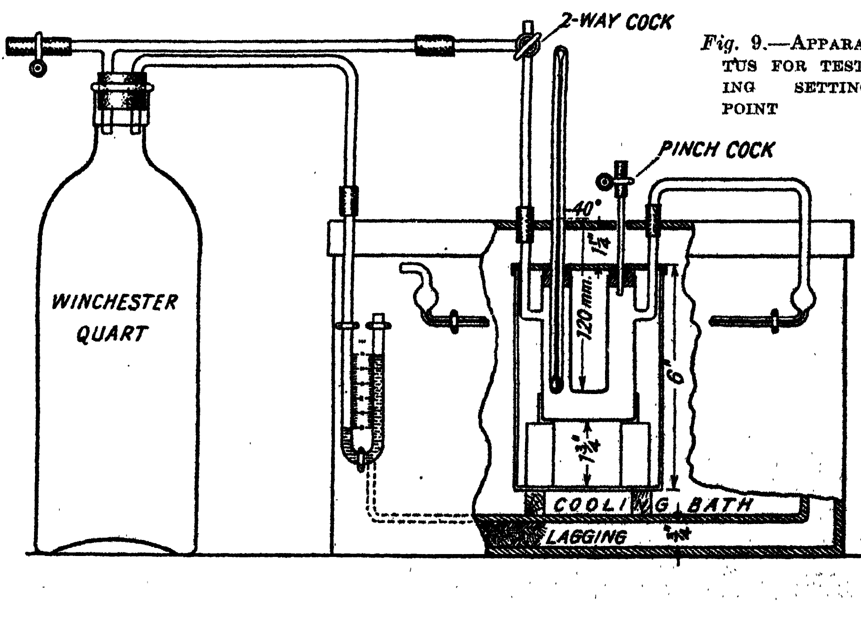


Fig. 9.—Apparatus for Testing Setting Point

As the oil cools, it reaches a temperature where it becomes cloudy, due to the crystallising of small solid particles. This temperature is the Cloud Point. On further cooling, the oil reaches a temperature when it only just flows when the vessel is tilted. This is the Pour Point.

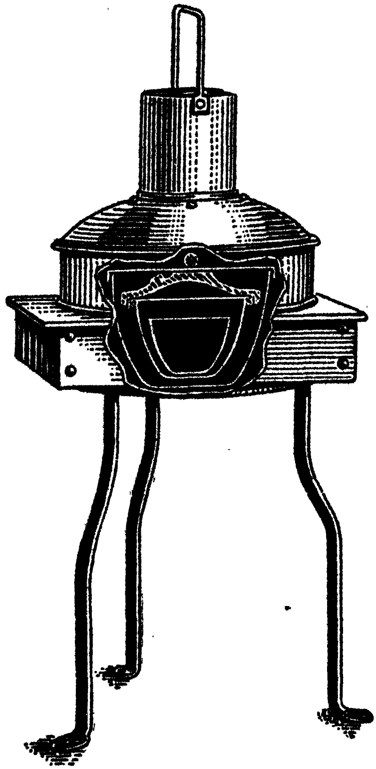


Fig. 10.—CONRADSON CARBON RESIDUE TEST APPARATUS

Cold Test Setting Point

At some temperatures below the pour point the oil ceases to flow altogether. This is known as the Setting Point. A U-tube of the form given in Fig. 9 is usually used for this test. It is surrounded by a freezing mixture, consisting of ice and salt, or, for very low temperatures, alcohol and solidified carbon dioxide.

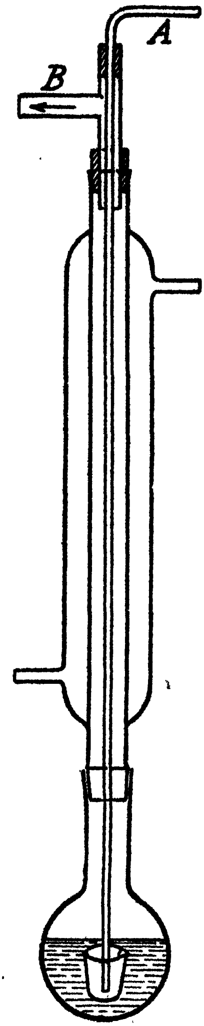


Fig. 11.—FLASK USED FOR SLUDGE TEST

Carbon Residue Test

This test determines the amount of "coke" or carbon residue left when an oil is completely evaporated. The Conradson apparatus is shown in Fig. 10. The sample is heated in a porcelain crucible which is enclosed in a larger iron crucible fitted with a lid containing a small hole. This crucible rests on sand contained in a still larger crucible, which is placed in a sheet-iron muffle. Heat is applied from below until all the vapour has been driven off. The weight of carbon remaining per 100 parts by weight of the original oil is the carbon residue number. This test is of some importance in oils for internal-combustion engines, as the carbon may be deposited in the engine cylinder.

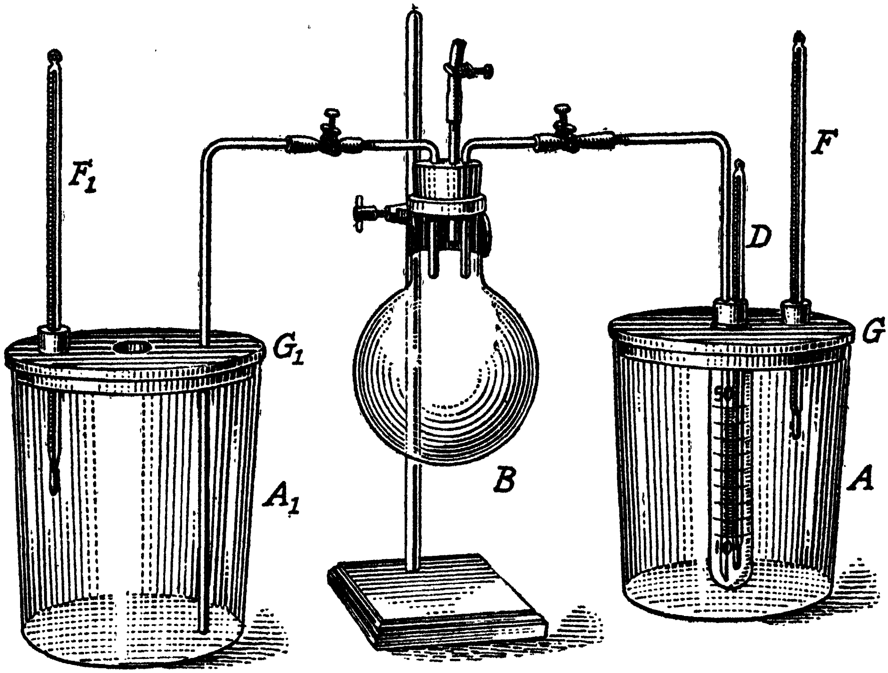


Fig. 12.—APPARATUS USED FOR EMULSIFICATION TEST

Sludging and Oxidation

In splash-lubricated engines or machines the oil is churned up and the oxygen in the air tends to combine with the oil. This oxidation may decompose some of the oil and form a " sludge," which may be harmful to the engine. Fig. 11 shows the flask used for this test. The oil in the flask is maintained at 302° F. for forty-five hours and a current of air is bubbled through the heated oil. The sludge produced is then carefully measured.

Demulsification Number

When an oil is churned up with steam or water it tends to form an emulsion. This is objectionable in steam turbines and engines, and an oil must be selected which resists this emulsification. The method of testing for this property is to thoroughly mix given quantities of oil and water and to measure the time for them to separate when allowed to stand. The apparatus is illustrated in Fig. 12.

Twenty c.c. of oil are placed in a graduated test tube. This is placed in the emulsifying bath (*A*), which contains 3 litres of water. The steam generator (*B*) is connected to the test tube by means of glass and rubber

tubing with a cork as shown. Thermometers D and F give the temperature in the test tube and bath. A separating bath ("A_1") also containing 3 litres of water is connected to the steam flask in the same way. The water in A_1 is brought to 200° to 203° F. and maintained at that temperature. The water in A at the commencement of the test is 67° F. Steam is admitted into the oil so that the oil is heated to 190° to 195° F. The steam flow is then adjusted to maintain this temperature. The steam condenses on meeting the oil and emulsification is continued until 40 c.c. of oil and water are contained in the test tube, the time being taken. The steam pipe is then removed and the test tube transferred to the separating bath (A_1). The time in half-minutes is then taken until 20 c.c. of oil have separated. This gives the demulsification number. A good oil should separate in less than five minutes.

The property of emulsification is, of course, desirable in some oils, such as are used for "cutting compounds." These "soluble oils" are mixed with water to form the emulsion used on machine tools for cooling the tool and metal, washing away chips, producing a smooth finish, and protecting the finished work from surface corrosion and rusting. Rich mixtures of

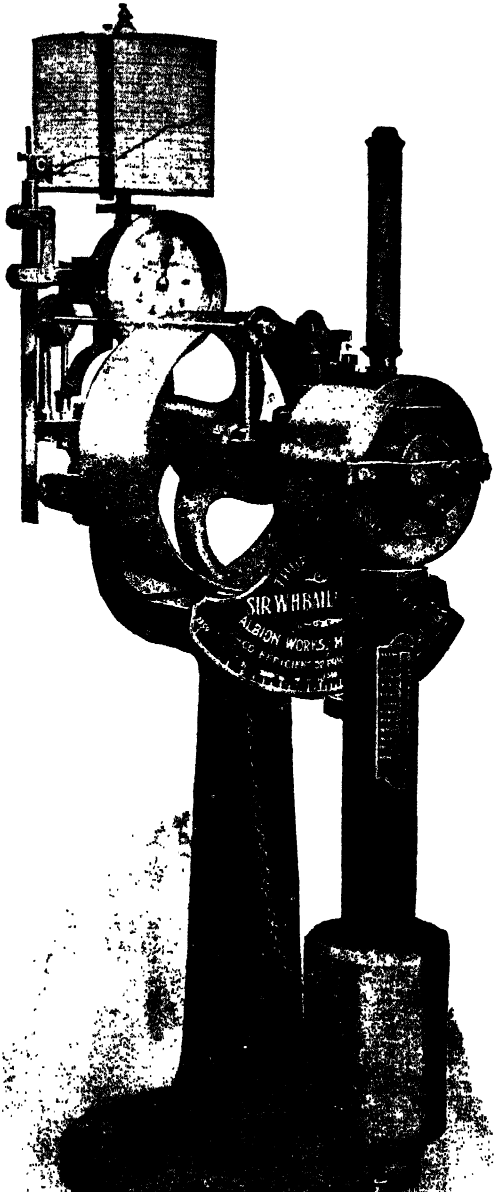


Fig. 13.—Friction machine for testing the efficiency of lubricating oils (*Sir W. H. Bailey & Co., Ltd.*)

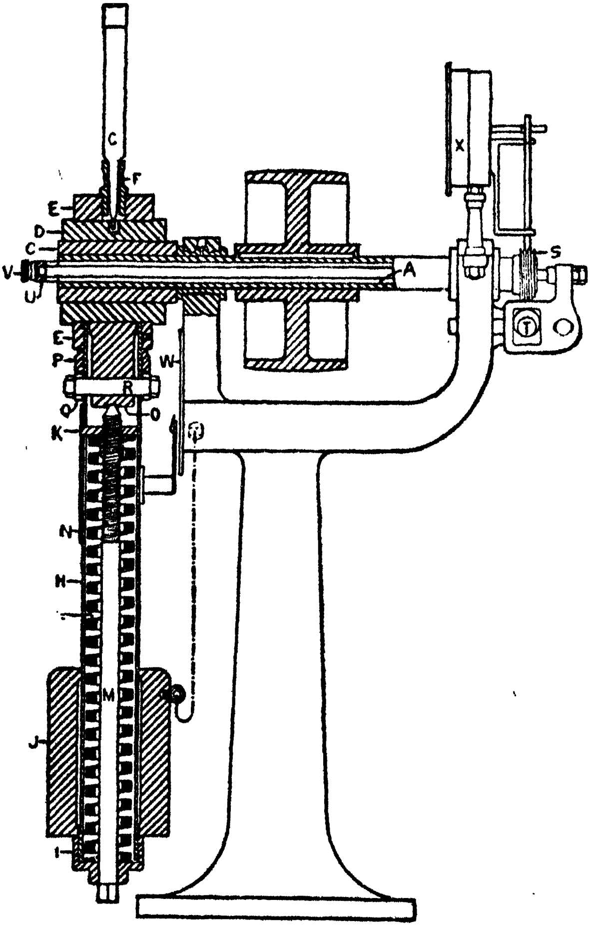


Fig. 14.—Section of "Thurston" friction machine
(*Sir W. H. Bailey & Co., Ltd.*)

animal or vegetable oils with mineral oils are usually used for this purpose.

Colour

The colour of oils varies from pale yellow to red, brown, and almost black. This colour may be judged by transmitted or reflected light, that is, by light passing through the oil or reflected from its surface. The colour test by itself is of small value, but it may help to distinguish between similar oils.

The colour test is done in a tintometer, which matches oils by means of standard colours consisting of coloured slides.

Mechanical Testing

When the efficiency of a lubricating oil is required, mechanical tests on friction machines have to be carried out. The ordinary type of testing machine is designed to determine the behaviour of a lubricant introduced between a shaft and bearing. The property known as oiliness is very important in lubricants. This property is of great importance in heavily loaded low-speed bearings. In such cases the oil film may be squeezed out and a condition known as "boundary lubrication" be set up.

Animal and vegetable oils possess better lubricating properties than mineral oils under such conditions, and oils are blended to give the re-

quired property. In the mechanical testing of lubricants, conditions under which the oil is to operate should be reproduced as far as possible.

A well-known machine for such tests is the "Thurston," made by Sir W. H. Bailey & Co., Ltd., Salford, and is illustrated in Figs. 13 and 14. This machine consists of a pendulum hung from a bearing on a shaft rotated by means of a pulley. The bearing is clasped by two brasses, and the pressure applied by the spiral spring inside the pendulum is regulated by means of a milled screw head. The pressure per square inch and the total pressure are indicated on the index plates. When the shaft is rotated, the friction between it and the brasses causes the pendulum to deviate from the vertical and the "coefficient of friction" is determined from the angle of deviation. The temperature during the test is indicated by the thermometer above the bearing. A drum indicator can be fitted as in Fig. 13 to record any variation of coefficient of friction as the test proceeds.

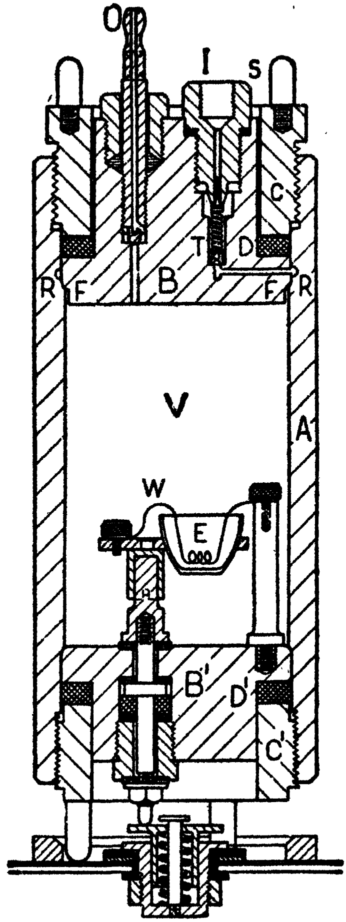


Fig. 15.—THE GRIFFIN-SUTTON BOMB CALORIMETER (*Griffin & Tatlock, Ltd.*)

Calorific Value

When a fuel oil is used, the calorific value must be known. This is the heating value of the oil and is expressed in Centigrade Heat Units (C.H.U.) per lb. or British Thermal Units (B.Th.U.) per lb.

The method of testing for calorific value is to burn a measured quantity of oil in a vessel called a calorimeter, the heat generated being absorbed by water surrounding the vessel. The temperature rise of the water is measured, and since the quantity of water is known, the heat generated by the combustion of the fuel may be determined.

Several types of calorimeter may be used for this test, the "bomb" type being commonly used. Fig. 15 illustrates the Griffin-Sutton bomb calorimeter. It consists of a thick-walled steel vessel with gas-tight joints at *B* and B^1. A small quantity of fuel is weighed in the crucible (*E*) and a short length of fuse wire (*W*) is fixed to a pair of terminals, the fuse wire touching the fuel. The bomb is assembled and a charge of

oxygen is passed into it through the valve (T) from an oxygen cylinder until the pressure in the bomb is about thirty atmospheres, the valve then being closed. A lifting handle is then screwed to the bomb and is used to insert the bomb into a water calorimeter. This is a larger vessel containing a weighed quantity of water, in which the bomb is immersed. Spring contacts for the electrical ignition are contained in the base and are shown in Fig. 15. When everything is ready, an electric current is passed through the fuse wire which ignites the fuel in the presence of the oxygen. The temperature rise of the water is measured by means of a very sensitive thermometer. Allowance must be made in the calculation for the water equivalent of the apparatus and for any loss of heat due to radiation.

If w is the weight of fuel burnt in lb.; W the weight of water, including the water equivalent of the apparatus, in lb.; t the temperature rise of the water with no heat loss in °F., then the calorific value of the fuel is given by

$$C.V. = \frac{W \times t}{w} \text{ B.Th.U. per lb.}$$

Illustrations of test apparatus have kindly been supplied by Messrs. Griffin & Tatlock, Ltd., A. Gallenkamp & Co., Ltd., and Sir W. H. Bailey & Co., Ltd.

INDEX